THE UNIVERSITY OF ALBERTA

AN INVESTIGATION INTO [illegible]

TURN PHASES IN TRAFFIC [illegible]

BY

© ROBERT HARRY [illegible]

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

FALL, [illegible]

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AN INVESTIGATION INTO SPECIAL LEFT TURN PHASES IN TRAFFIC SIGNALS

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ABSTRACT

The purpose of this investigation is to closely scrutinize lead and extended left turn phases and to determine criteria to be considered when confronted with the decision of installing special phasing. Factors considered include Volume handling capacity, Delay, Comprehension of signal, Reaction to the display and the Safety aspects of such an operation.

Data reviews to evaluate these factors were;-before and after volume counts, intersection movement counts, intersection delay counts and before and after accident records.

The tests were conducted in the City of Edmonton. Flash phase signals were installed in the City in 1966. Members of the City staff have conducted several tests concerning their operation, all of which were available to this study.

Results of the tests indicate that the split phase signal is a logical and efficient installation displaying a high left turn volume. Analysis of accident occurrence indicated little or no increase in overall accident total due to the installation of the split phasing.

The principal conclusions from the tests were

1. Split phase signals have a high volume handling

capacity.

2. Split phasing should be considered when opposing volumes reach 1000 VPH or more, or when the warrants set out in this report are exceeded.

3. Careful examination of intersection characteristics will allow the determination of need for special turning phases, the type of phase which would be preferable and other considerations which will increase the traffic handling efficiency.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Associate Professor J. J. Bakker of the Department of Civil Engineering at the University of Alberta, Edmonton for his interest, guidance and advice throughout this study.

This project was made possible through the financial aid made available from the Traffic Engineering Division of the City of Edmonton Engineering Department with approval of the City Commissioners.

Appreciation is extended to B. M. Huffman, Traffic Engineer for the City of Edmonton, for his continued encouragement and support throughout the program. The interest and help of several members of the Traffic Division, who were involved in field tests, was essential to the completion of the project.

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I would also like to thank my wife for her patience and assistance throughout this study.

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CHAPTER I

INTRODUCTION

The traffic control signal was initially introduced to safely and economically alternate the right of way at street intersections. The increasing use of the signal device attests to the fact that it does provide the safest, most efficient means of controlling vehicular traffic for the least cost. The attempts of urban engineers and planners have failed to date to produce a more efficient system.

Although the basic concept of assigning right of way by a visual display has been retained the technological advances of this era have allowed vast improvements in operation and use of traffic control signals. The signal has progressed from the original hand switched display, to the mechanically switched pre programmed signal, to the electronically switched vehicle actuated control and today vast networks of signals are being operated by a central control which continually samples traffic movements and assigns new cycle timings.

The enigma of the signal controlled intersection has

been the turn across the path of traffic in the opposing direction or the left turn (the right turn for left hand drive countries such as Great Britain). The left turn requires either the turning vehicle or the vehicle from the opposing direction to stop to allow the other to pass. This action is an additional right of way conflict and one which the standard two phase traffic signal does not control.

Traffic Engineers presently use several methods of handling the left turn vehicles. However, all methods sacrifice efficiency and/or safety to provide for the left turn movement. The present approaches being used are generally one of the following or a combination of the following.

1. Provision of protected left turn area (bay) through geometric design.

2. Provision of a special left turn phase controlled by special signal heads.

3. Utilization of multi phase operation (an approach leg with heavy left turn has a phase to itself.)

4. The splitting of opposing green times to provide

either a lead (advanced) or a lag (extended) time for left turns.

The presently accepted Canadian approach to the left turn problem as described in the "Uniform Traffic Control Devices for Canada Manual" (1) is briefly:

1. Two phase operation is recommended if left turns from any one pair of opposed approaches is at all times less than 20% of the through volume in the heavy direction.

2. Advanced or Extended green phases could be considered if left turns from any one pair of opposed approaches exceed 10% of the through movement in the heavy direction.

3. Three phase signals should be considered if the sum of right and left turns into any approach during the four test hours exceeds 50% of the through volume in the heavy direction.

In addition to the above in 1968 the Standard was revised to include a standard indication of Advanced or Extended green phases. The display adopted was the utilization of a flashing green arrow in conjunction with a standard green ball indication.

PURPOSE OF THE THESIS:

This investigation deals with the use of Advance or Extended left turn phases. The ultimate aim of the study is to provide a means of reviewing any given signalized intersection to determine the requirement for and the type of special phases to handle left turning movements.

The parameters to be assessed are:

1. The volume capabilities of the intersection.
2. The delays encountered in the intersection.
3. The effect on Safety of the various devices.

LIMITATIONS OF THE STUDY:

The prime limiting factors of this study are the amount of adequate data available and the time and means to review the volume of data required to assess each individual intersection. This study was restricted to a chosen limited number of intersections within the Edmonton area. Ideally an infinite number of intersections throughout the continent should be utilized. The data is collected by manual observation as no proper recording equipment was available.

ORGANIZATION OF THE THESIS:

The problem of left turns at signalized intersections

has been the subject of years of research and numerous studies. Therefore the initial step in this investigation was a review of literature on the subject and presentation of the more pertinent theories and practices presented in Chapter II.

Existing split phase traffic control signals in the Edmonton area were observed in the field. Volume and delay data were obtained and accident records for these intersections reviewed. These data were analyzed and compared to obtained data for two and three phase signals. Significant differences in Capacity, Delay or Accidents was assessed.

Using these data the signal timing requirements plus the accident potential of various signals were assessed. This was followed by a discussion and comparison of the various control methods being investigated. The final chapter of this thesis contains the conclusions and the recommended actions of the investigations.

CHAPTER II

REVIEW OF LITERATURE PERTAINING TO SPECIAL LEFT TURN PHASES

The amount of written data concerning left turns at signalized intersections is not voluminous. When one considers that this is a basic consideration in signalizing intersection, the lack of detailed studies on the subject is surprising.

The practising engineer in a field application would logically refer to the "Manual on Uniform Traffic Control Devices for Streets and Highways" (2) in the United States or its counterpart the "Manual of Uniform Traffic Control Devices for Canada". (1)

A. MANUAL REVIEW

The U.S. manual (2) makes provision for the installation of special turning indications but does not suggest either warrants for left turn phases or left turning volumes which should receive special attention in signalization. The Canadian manual makes these provisions

Two-Phase Operation:

i. The volume of left turns from any one of a pair of opposed approaches is less than 20% of the through volume in the heavy direction.

ii. The sum of left and right turns onto any approach is less than 50% of the through movement in the heavy direction.

Split Phase Operation:

i. The number of vehicles making the turn exceed 10% of the through movement.

Three Phase Operation:

ii. The number of vehicles making left turns from any pair of approaches exceed 20% of the through volume in the heavy direction.

iii. The sum of right and left turns into any approach exceeds 50% of the through volume in the heavy direction.

The Canadian Manual (1) describes in detail the specification for operating either the Advanced or Extended green phases. The system being simply the use of a flashing green

arrow pointing in the direction of the left turn displayed in conjunction with a green ball. The flash phase to be followed or proceeded by a steady green clearance phase depending on whether an advance or extended phase is employed.

B. EMPIRICAL REVIEWS

Matsun Smith & Hurd in their complete text book "Traffic Engineering" (3) discuss left turns in two different chapters from two points of view. In chapter 8 "Intersection Characteristics" critical gap is examined. Critical gap being described as the size of gap or lag required for crossing flows of traffic. Reference is made to F. J. Kaiser Jr's (4) study wherein he determined that left turn drivers refused all gaps less than 3.75 sec. and accepted all gaps 4.75 secs. or greater. The median value of accepted gaps being 4.25 sec.

In Chapter 21 "Traffic Signals" Matsun, Hurd and Smith (3) make the following suggestions.

> "The objective of phasing is to accommodate all traffic movements with increased safety and minimum delay. Safety urges a phasing which will reduce or eliminate all potential conflict. Consideration for minimum delay impells a phasing which will accept as many simultaneous flows as practical, to achieve a high volume of accommodation. The use of leading or split phase green to accommodate turning or other irregular movements is an example of ingenuous phasing."

"The number of distinct phases employed should be kept to a minimum consistent with safety and facilitation. The selection of flows in each phase should develop the minimum frequency and severity of conflict and the sequence of phases should minimize waste time."

Studies have shown that through vehicles take on the average 2.1 seconds to clear an intersection. Left turning vehicles take an addition 1.3 seconds or 2.1 + 1.3 = 3.4 seconds or for application in formulas one left turning vehicle is equal to $\frac{3.4}{2.1} = 1.6$ through vehicles.

The "Traffic Engineering Handbook", (5) the third edition of which was published in 1965, discusses leading and lagging phases plus multiple phases as follows:

"Leading or Lagging Greens are not exactly a third phase but useful in special situations.

Lead - preceeds opposing through

Lag - follows opposing through

The use of either should be approached with extreme caution because motorist approaching from shorter green phase may not realize it since he sees opposing traffic moving freely.

Some authorities feel leading green is probably less hazardous than the lagging green because motorists in opposing directions would generally be starting from a stopped position.

On the other hand lagging green is favoured because of a tendancy for traffic standing at the Stop lines in the opposing direction to start when they see the traffic having the leading green begin to move. They feel that the left turn capacity is increased because the front left turning vehicles have moved into the intersection during the regular green period and a greater number of vehicles are able to clear the intersection than when they are starting from the Stop line at the beginning of a leading green interval.

Three Phase Signals - every effort should be made to avoid extra delay caused by three phase operation."

The third text book of the three basic texts, "Traffic Engineering", (3) "Traffic Engineering Handbook" (5) and "The Highway Capacity Manual (HRB 87)" (6) gives methods for calculating left turn capacities. These are:

A. Turns with separate Turning Laws and/or Separate Signal Indications.

1. Separate Turning Lane-Signal Controlled
   - deduct width of special lane from total width phase calculate through capacity with 0 lefts
   - turning lane service volumes per 10' width

Level*	Veh. per hr.	o/o Tr.
ABC	800	5
D	1000	5
E	1200	5

-two or more turning lanes the above X 0.8 for additional lanes.

(apply appropriate G/C factor for separate lane signal)

2. Separate Turning Lane-No Signal

- as above for through movement

- service volume = 1200 - total opposing traffic volume in opposing direction in terms of passenger car per hour of green.

3. Separate Signal (No separate lane)

i.e. leading or lagging greens.

- apply basic intersection capacity procedure to entire width.

- for special phase calculate based on left turns from one-way street.

These alternatives assume that the likelihood of through vehicles becoming "trapped" behind a turning vehicle is no greater than at an ordinary two phase operation. This

*Level of service explained on page 51

assumption is not always valid particularly if left turning not allowed during through phase or through not allowed during left.

The preceeding excerpts are from texts and manuals and could be termed basic review in Traffic Engineering. Papers concerning current practice will now be reviewed.

Probably the most complete report on existing practice of utilizing split phases is the article "Leading and Lagging Greens in Traffic Signal Control" (7) which is the informational report of the Institute of Traffic Engineers project committee 4F (62). The article appears in the April 1966 issue of "Traffic Engineering".

The report is based on data collected from 102 Cities, Countries and States throughout North America. Of interest is the fact that 71 out of 75 Cities, 3 out of 7 Countries, and 11 out of 20 States reporting used leading or lagging greens, thus attesting to their wide use and the requirement for a standard display of split phases.

Pertinent facts from the report are:

1. Usage and Type of Signal Control.

6.9% of the signals reviewed utilized leading or lagging phases. i.e. 2,333 signals out of 33,971.

2. Signal Indications.

The most popular means of indicating the special interval was the steady green arrow displayed with a steady green ball. Second most popular was the eastern Canadian flashing green ball. (Note: the Canadian standard is now flashing green arrow displayed with a green ball).

3. Clearance Interval.

Of 85 replies - 37 did not use a clearance interval following leading greens and 33 did, and 9 did not use a clearance preceeding lagging green with 56 utilizing a clearance interval.

4. Cycle Lengths and Lead-Lag Intervals.

Cycle lengths varied from 28 - 240 seconds, average varying from 94.9 seconds maximum to 54.8 seconds minimum. The split phases varied from 20.7 seconds to 6.7 seconds with some agencies reporting that the lead lag intervals were reduced to 0.8 seconds to 2.0 seconds during off peak periods.

5. Preference for Leading or Lagging Green Interval Selection.

47.5% of traffic engineers preferred leading phases

and 32.5% preferred lagging phases while 20% utilize both.

The Pros and Cons of the split phases are listed as:

I. LEADING GREEN

A. Advantages

1. Permits higher intersection capacity on restricted width roadways, compared with two-phase traffic signal operation.

2. Reduces traffic congestion by clearing the left turning vehicles through the intersection first.

3. Easier to program in the traffic signal controller, since less intervals are required than in a lagging green.

4. Easier to adjust in the traffic signal controller to minimum time during off-peak periods.

5. Eliminates conflicts between left turn and opposing straight through vehicles by clearing the left turn vehicles through the intersection first.

6. Driver reaction time is quicker.

7. Requires only one amber clearance interval at the end of the straight green phase.

8. Desirable where left turn lanes do not exist.

9. Can be used to provide co-ordinated progressive traffic movement in an interconnected signal system with unequal spacings.

B. Disadvantages

1. Creates vehicle-pedestrian conflicts during the leading green interval.

2. Left turns may pre-empt the right-of-way from the opposing straight through movement when the green is exhibited to the stopped opposing movement.

3. Opposing movement may make a false start in an attempt to move with the leading green vehicle movement.

4. Actuated lead does not extend to normal beginning of straight through green and permits the opposing movement to arrive ahead of the green indication at the next signalized interconnected intersection in progressive traffic signal systems, where progressive movement is based on beginning of straight through green.

5. Does not conform with the normal right-of-way and

creates entrapment of the left turn vehicle operator when the leading green interval expires, causing the left turn driver to receive a traffic ticket for negligent collision or failure to yield right-of-way if involved in an accident.

II. LAGGING GREEN

A. Advantages

1. Conforms to the normal left turn right-or-way law and does not create entrapment of the left turn vehicle operator.

2. Closer to normal driving behaviour of vehicle operators.

3. Does not create head-on conflicts between vehicles as the leading green does.

4. Provides for vehicle-pedestrian separation as pedestrians normally cross at the beginning of the straight-through green interval and pedestrian clearance has been completed at beginning of the lagging green interval where pedestrian signals are used.

5. Both directions of straight through traffic start at the same time, thereby giving greater straight through capacity.

6. Less time needed for the lag since left turns can filter through the opposing gaps during the time the straight through indications are exhibited.

7. Left turns do not pre-empt the right-of-way from the opposing straight through traffic movement.

8. Cuts off only the platoon stragglers from adjacent signalized interconnected intersections.

9. Desirable where a left turn lane exists.

10. Can be used to provide co-ordinated progressive traffic movement in an interconnected signal system with unequal spacings.

B. Disadvantages

1. Creates conflicts for the opposing left turns at the beginning of the lag interval since the opposing left turn drivers think that both movements stop at the same time. (Many traffic engineers feel that the left turn from the approach opposite the lag need be prohibited to remove the accident potential).

2. Creates an obstruction to through movement during the initial green interval where a left turn lane does not

exist, thereby, reducing the intersection capacity.

The report concludes with an analysis of the replies. The final recommendations suggests a warrant for the use of split phases should be established and that research in this area is required.

Benjamin W. McKay (8) suggests left turn phases should not be used:

1. Where they may cause an excessive delay to left turning vehicles.

2. At the meeting point of platoons in progressive systems.

A novel suggestion in this article is a warrant for left turn phases based on the number of left turns made on amber or red. Mr. McKay suggests that if an average of two or more left turns are made per cycle on the yellow and red portions of the cycles during the peak half hour, then the chances are good that there is excessive left turn delay.

Barry W. Fairfax(9) studied four left turn displays for exclusive left turn lags.

1. Green arrow (exclusive phase).

2. Green ball (standard 2-phase).

3. Flashing yellow (similar to Canadian flashing green).

4. Flashing red.

His findings were:

Efficiency of operation. i.e. Comprehension by motorist.

Green arrow - 100%

Green ball - 63%

Flashing yellow - 77%

Flashing red - 30%

and with regards to delay:

Indication	Vehicles Exceeding 6 Sec. Starting Time	Range (seconds)
Green arrow	0	-
Green ball	4	8.2 - 28.4
Flashing yellow	1	48.0
Flashing red	8	7.6 - 55.4

He concludes by recommending the use of a flashing yellow phase for left turning movements during 2-phase operation. (i.e. A split phase as opposed to multiphase arrow indication).

The final analysis of signal requirements will undoubtably involve a comparison of the efficiency gained by utilizing special turning phases versus deterents such as accident experience associated with the implementation of

of turning phases. Gurnett (10) studied three intersections in detail. Before and After delay studies were utilized to find how much intersection delay increased after minor left turn phasing was installed. His conclusions were:

1. Intersection delay increased from 22% to 121% after the left turn phases were installed.

2. Left turn delay is not substantially reduced by left turn phasing.

3. Normally, intersection delay costs outweigh accident reduction savings, but accident savings should be considered for each individual intersection.

The lead and lag intervals in signalization are similar to general signal studies. Some pertinent general papers were reviewed and are introduced below.

One problem of concern in considering signal design is starting response. Can the vehicular movement at a signal in a city of two million be compared to the same type of signal in a city of 20,000? One authoritative study in this field was carried out by E. T. George Jr. and F. M. Heroy Jr. (11). Data from five New Orleans intersections was collected and plotted to indicate starting response.

Data were collected by recording the first through 10th cars passage time from the time the controlling signal turned green until the vehicle started to move.

The results of the study are as in FIGURES 1, 2 & 3.

One possible use of this data would be to compare varying city size and weather conditions and hence determine signal timings and evaluate comparative studies.

C. THEORETICAL REVIEWS

A study closely associated to special left turn phasing is R. E. Hom's (13) paper, "Intersection Capacity of Exclusive Turning Lanes", in the March 1968 edition of Traffic Engineering.

The basic formula for determining capacity is presented as:

Separate Signal Control:

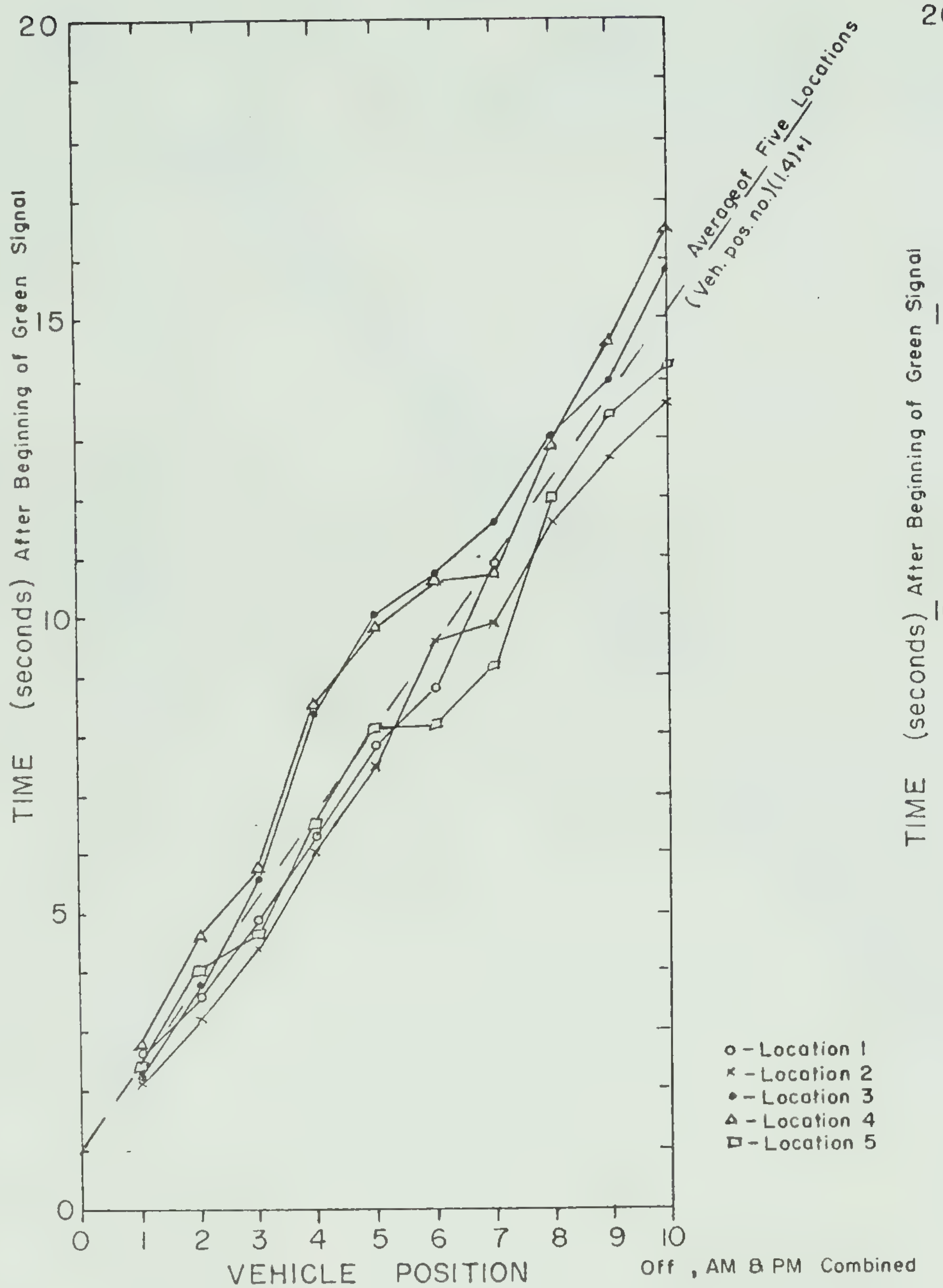
$$SV = AV \times G/C \times TF \frac{AW}{\Sigma 10} \quad 1 + (\Sigma - 1)\ 0.8$$

Without Separate Signal Control:

$$SV = \frac{(1200 - OT)}{TFOP} \quad \frac{G}{C} \times \frac{AW}{10} \times TFAP$$

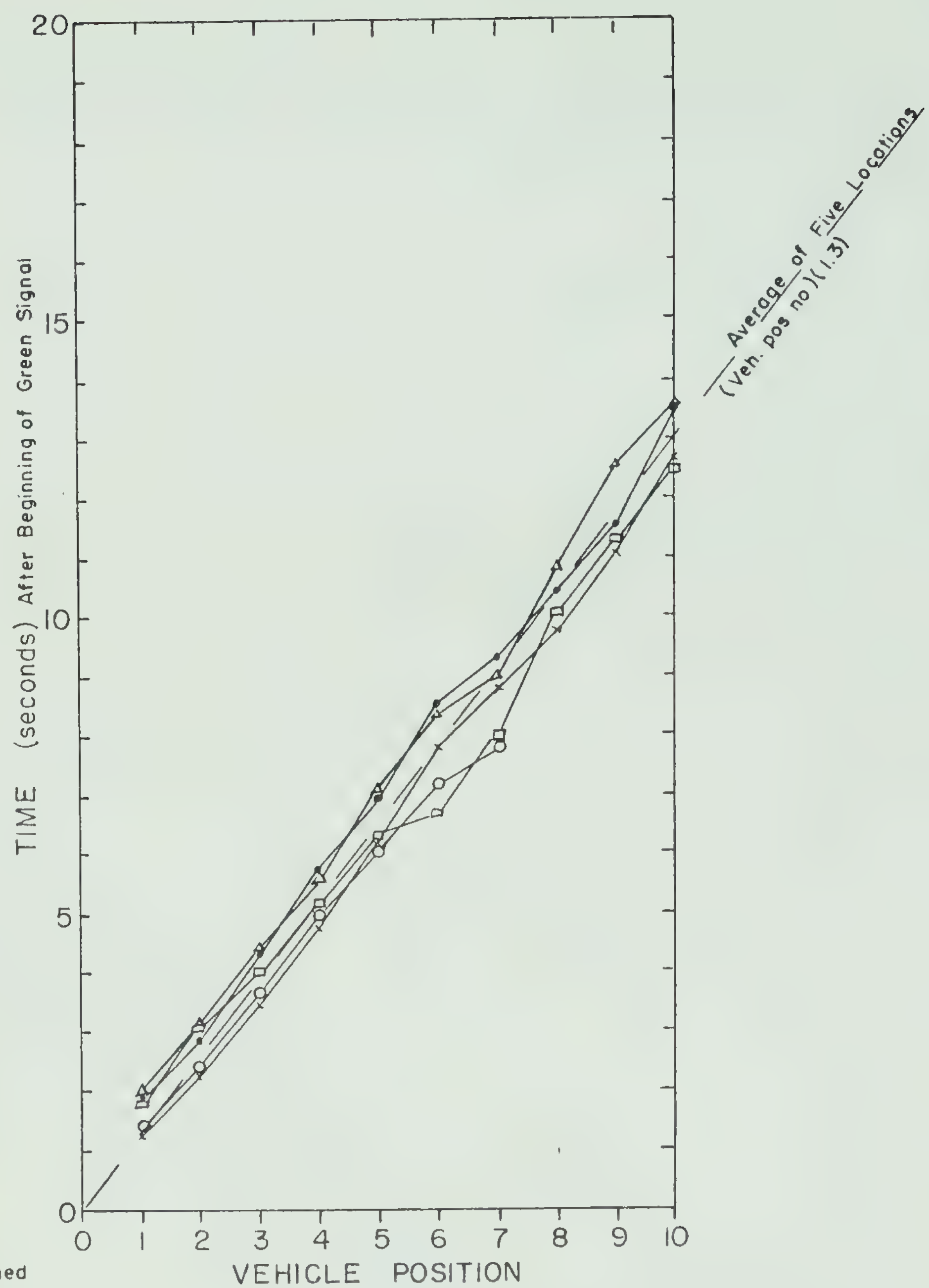
or

$$SV = 2 \left(\frac{3600}{C} \times \frac{AW}{10}\right)$$



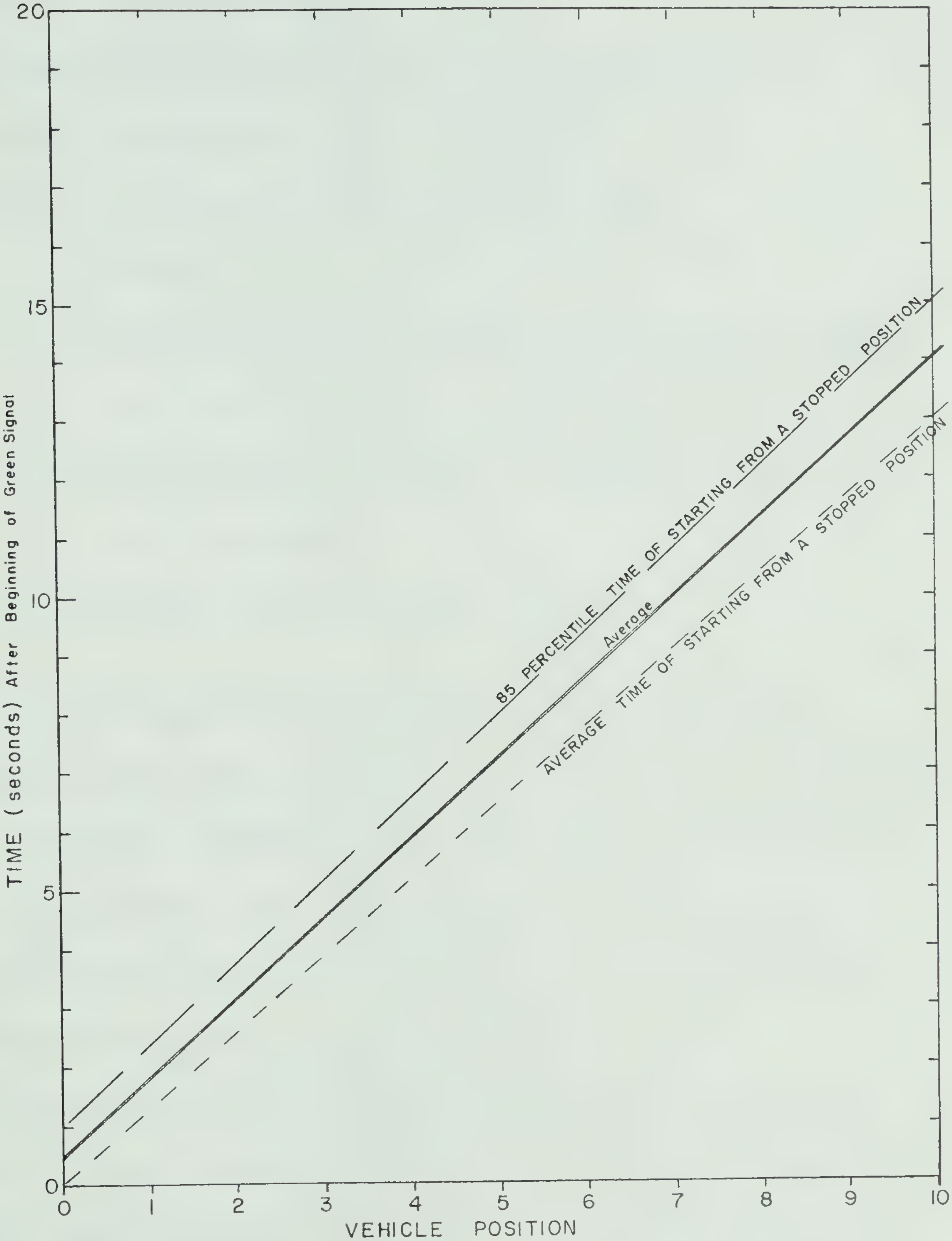
85th Percentile Time of Starting

Figure 1



Average Time of Starting

Figure 2



Comparison of 85 Percentile
& Average Time

Figure 3

whichever is larger where

SV = service volume

G/C = green phase time to cycle time ratio

TF = adjustment factor for trucks

AW = turning movement approach width

B = number of lanes

AV = approach volume in vehicles per hour of green per lane based on 10' lanes and 5% trucks

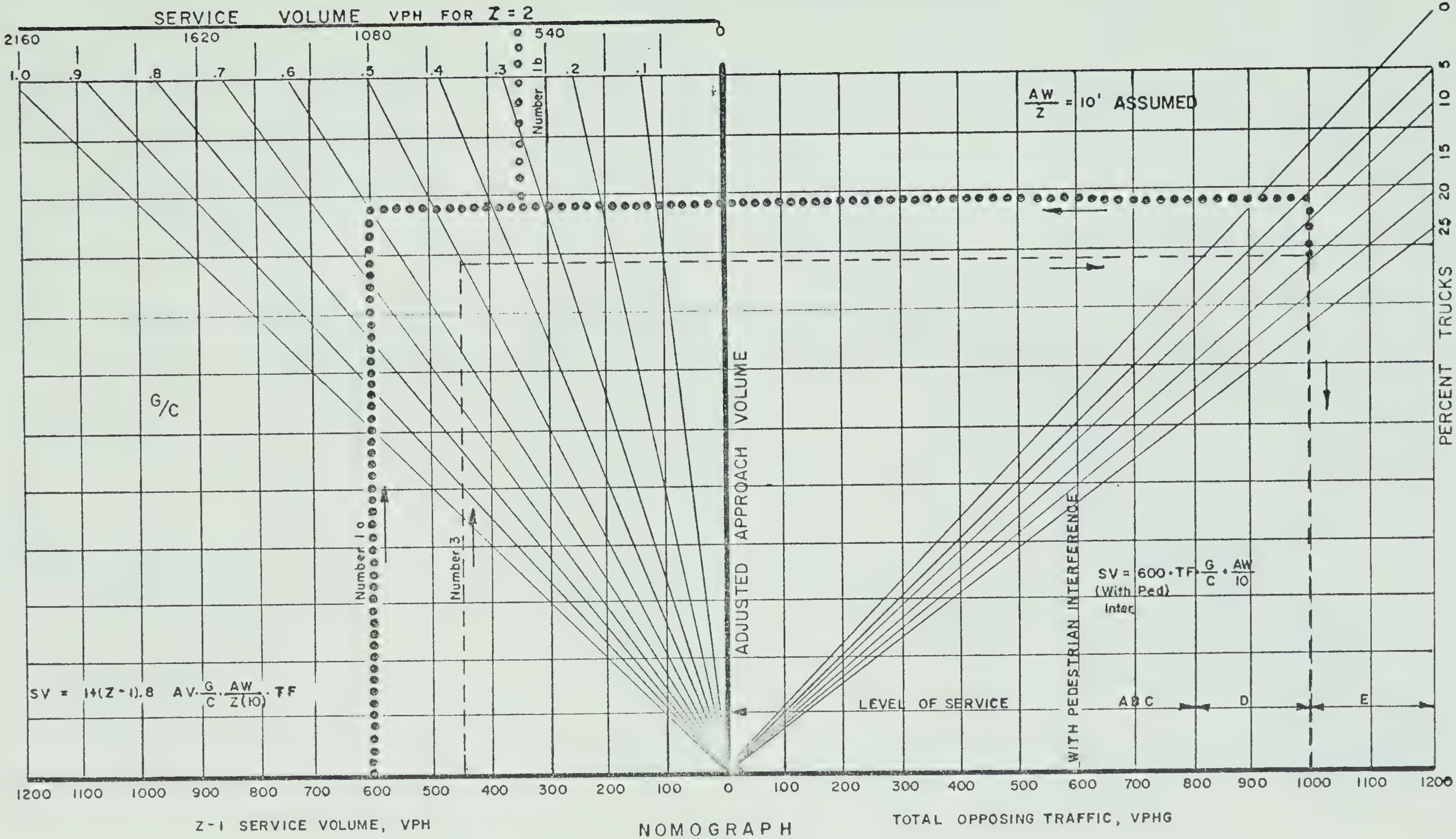
OT = total opposing traffic volume in vehicles per hour of green

C = signal cycle length in seconds

from this data nomographs were developed as shown in FIGURES 4 & 5, thus presenting a simple means of establishing left turn lane capacities in a more accurate method than that presented in "The Capacity Manual" and a means of evaluating left turn volumes in such a manner that they could be utilized in a warrant system.

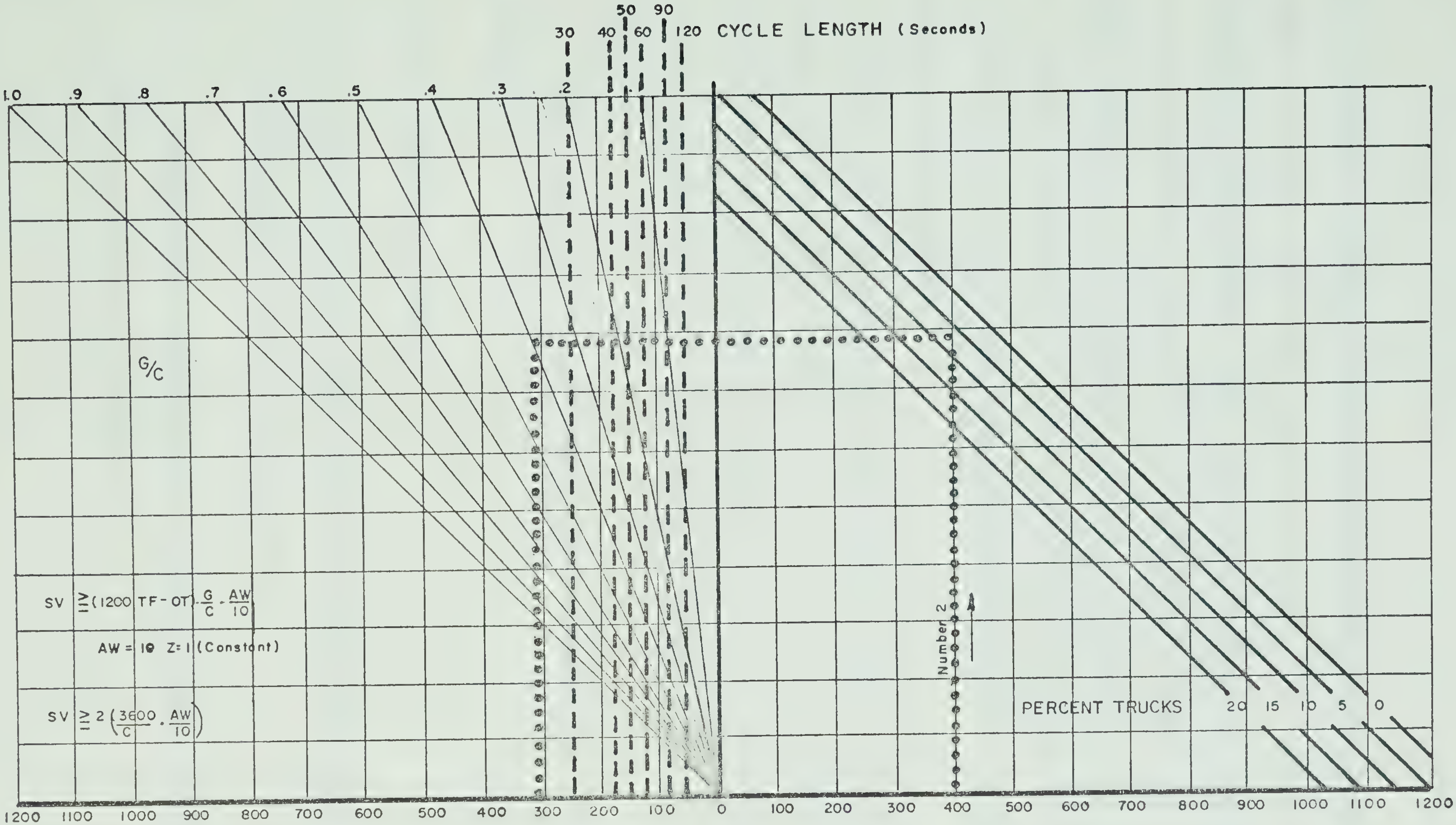
The National Co-operative Highway Research Program Report 32 (14) presents one of the most complete reviews of signal timing and its effects on the efficient movement of traffic. The summary suggests;

"The results (of this study) dramatically illustrated



NOMOGRAPH
FOR
THREE PHASE AND RIGHT TURN TWO PHASE SIGNALS

Figure 4



NOMOGRAPH
FOR
LEFT TURN LANE AT TWO PHASE SIGNAL

Figure 5

the reduction in delay experienced whenever efficiently timed two-phase operation can be employed. An inescapable conclusion that emerged time and again during the project was the overiding influence of signal-cycle length on effectiveness of performance. Traffic Engineers are urged to conduct thorough studies of individual intersections and systems and to strive for the reduction of cycle length wherever appropriate."

The study was based on a simulation model utilizing theoretical considerations and past empirical findings. The portion of the study of interest is that concerning the effectiveness of phasing schemes incorporating turn controls.

Four signal phasing schemes were selected for detailed study.

1. Simple 2-phase.

2. Leading split phase with protected left turn in one direction only on each street.

3. Leading and lagging split phases with protected left turns in all directions.

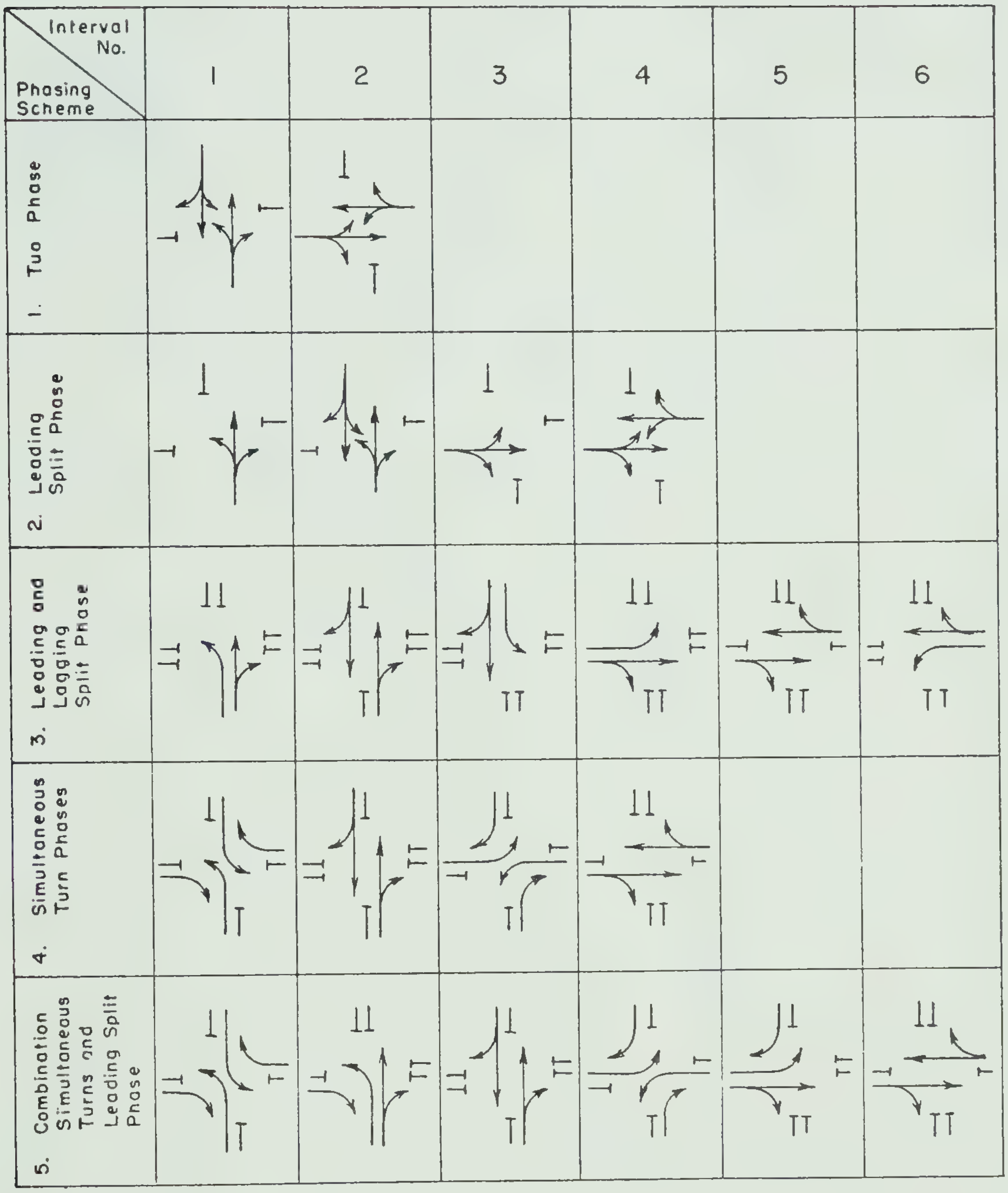
4. Simultaneous left turn phases.

These are shown in FIGURE 6.

These phases are considered by the author to be impractical for field installation, nevertheless, the data does illustrate the effect of multi phasing. The report indicates that at all total interesection volume levels, the two phase operation is more efficient than multi phase schemes. Surprisingly, the evidence indicates an increasingly significant advantage of two phase signalization as traffic volume rises, as shown in FIGURE 7.

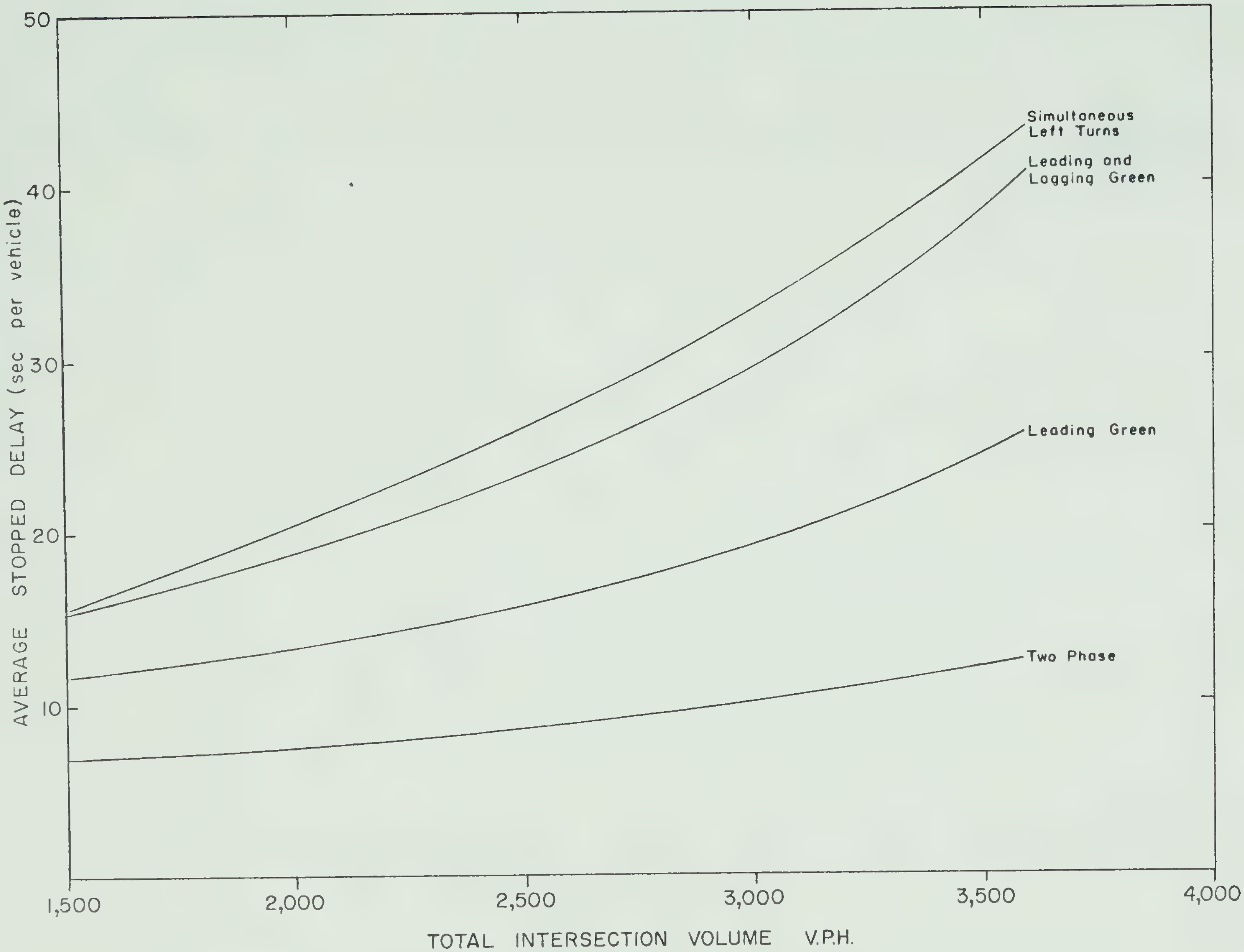
The distribution of traffic proved to be an important factor and in fact these directional imbalances proved a cause for a less effective operation for all multi phase signals except the leading green case, as shown in FIGURE 8.

The basis for the simulation model is the calculation of the queue discharge rate. The rate was calculated by an iterative process and produced a discharge Time-Space diagram as shown in FIGURE 9.



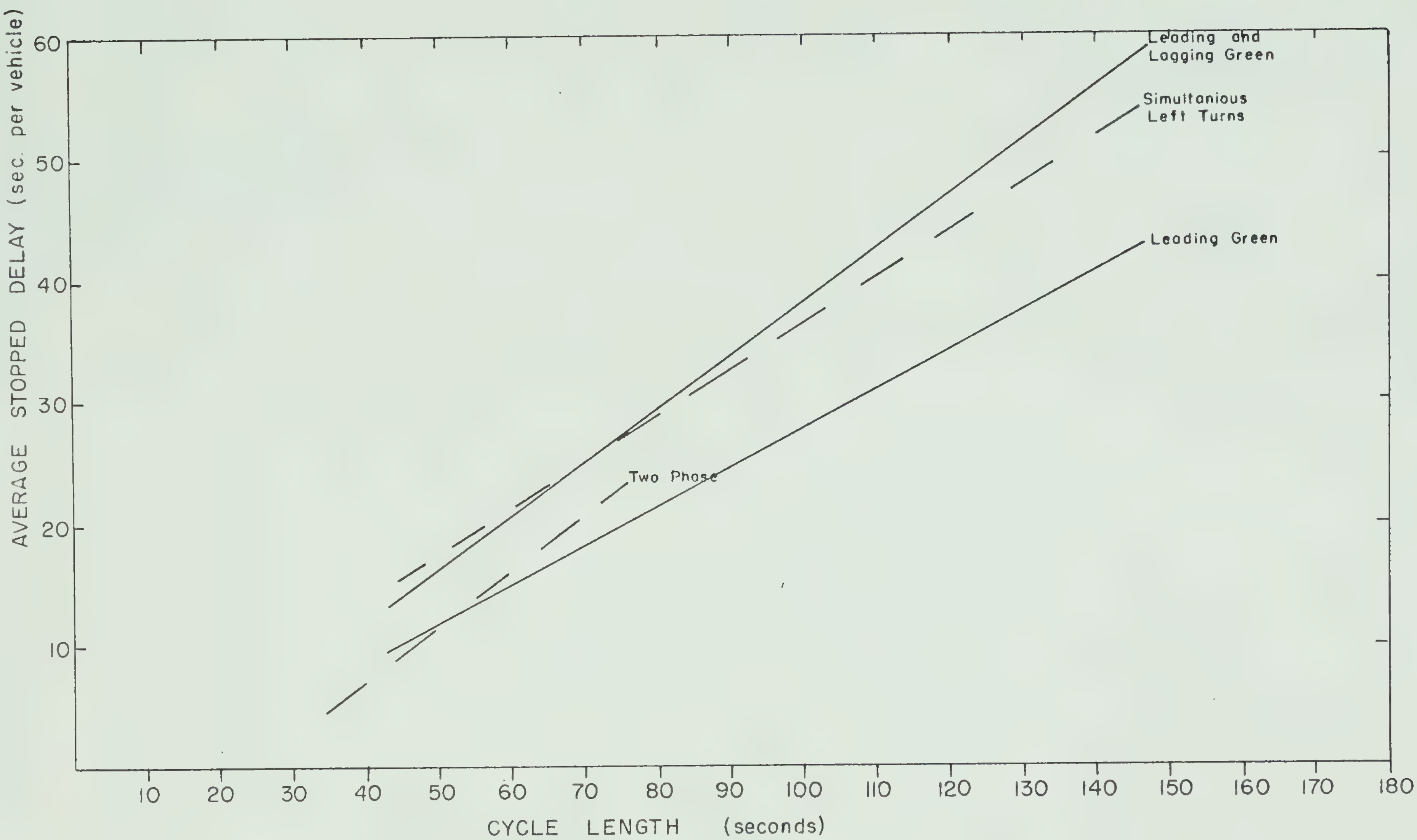
Signal Phasing Schemes

Figure 6



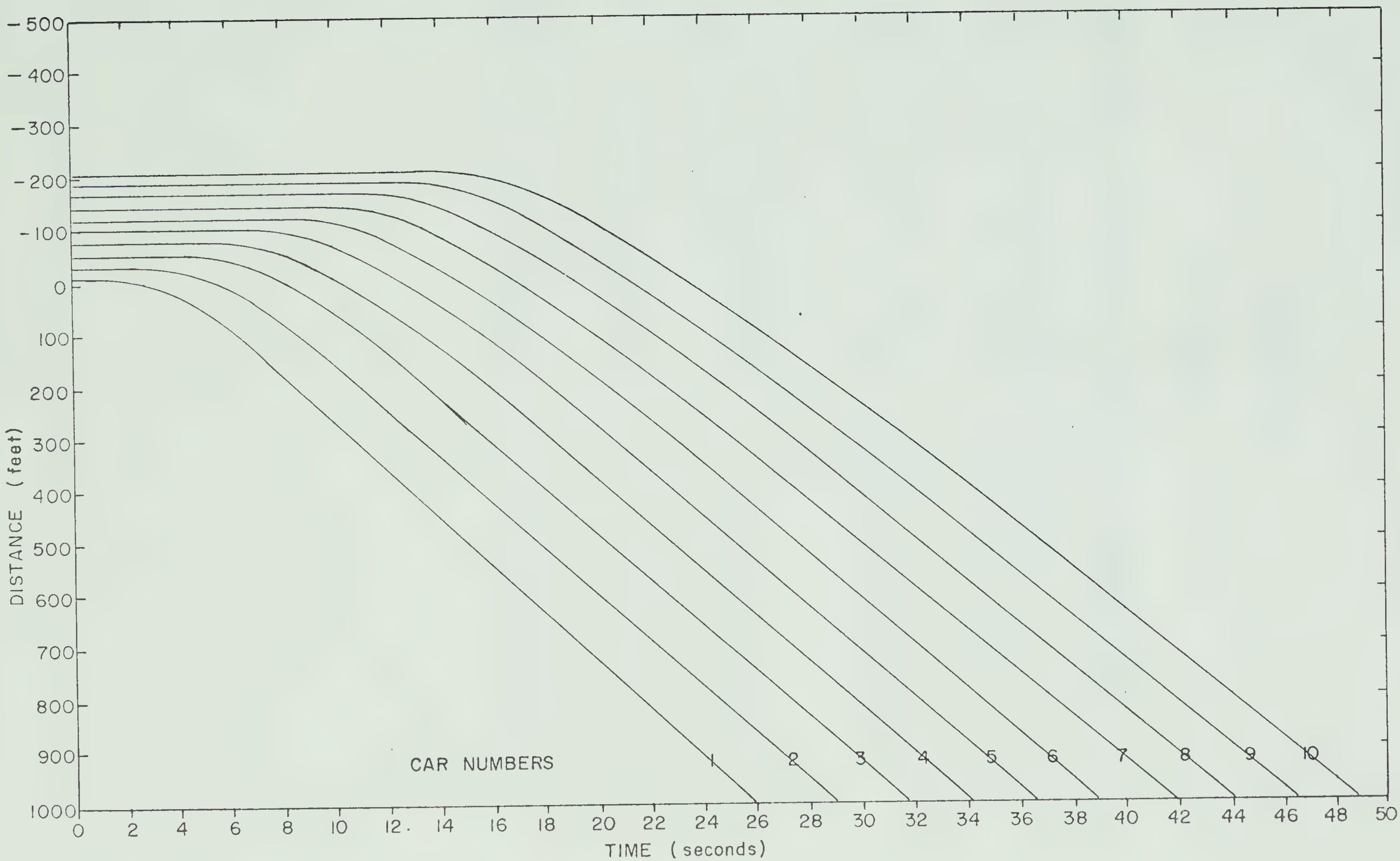
Effectiveness of Phasing Systems

Figure 7



Dependence of Average Stop Delay on Signal Cycle Lengths

Figure 8



Simulated Starting Graph

Figure 9

CHAPTER III

THEORY

The theory of left turn phases, whether they are advance, extended split phases or separate left turn phases is simply that the left turn is provided for in the signal operation. The turn phase is expected to provide the necessary left turn capacity with a minimum overall delay and accident exposure.

To the author's knowledge no nationally acceptable left turn warrant exists. The Canadian Manual (1) guidelines for two phase and split phase installations are a guide only and, as will be shown later, are applicable to only a very small range of intersection movements.

CHAPTER IV

DATA COLLECTED

This study utilizes a large amount of data. A large portion of the data was obtained from City of Edmonton Traffic Engineering Division Records. Other data were collected specifically for this study. A brief resumé of the records used, data collected and the methods of collection is presented below. Typical data sheets are shown in Appendix C.

A. TRAFFIC ENGINEERING DEPARTMENT DATA

i. Intersection Counts. The City has maintained intersection counts covering all major intersections since 1965. These counts show all intersection movements, percentage of commercial vehicles and buses in the intersection, number of pedestrian movements and their direction, sample vehicular delays and cycle lengths plus any remarks of observers. These observations are usually made during the morning and afternoon peak periods plus off peak samples. The sample day in all cases was Tuesday.

ii. Traffic Accident Records. All traffic accidents

in the city are reported to the City Police who in turn complete a standardized accident form. These data were then forwarded to the Traffic Engineering Department and recorded. This information is on file and complete data is available from 1948 to the present.

iii. Traffic Signal Timing. Timing sheets for all traffic signals plus their amendments and amendment dates are maintained in the Engineering Department.

iv. Intersection Observation. Traffic Engineering Personnel made intersection reviews of flash phase signals when they were first installed. Their observations are on file.

B. DATA COLLECTED FOR THIS STUDY.

i. Observation of Flash Signal Operation. Vehicular movements at several intersections were made to observe motorists reaction. All left turns were recorded and classified as to which portion of the cycle the turn was made in. Peak periods and off peak observations were made on a total of 11 intersection legs.

ii. Left Turn Delays. The delay experienced by left turning vehicles was recorded on 14 intersection legs. The observer recorded the delay of every 10th vehicle approaching the intersection in the left turn lane. The delays were timed for two hours in the morning and afternoon peak periods and for one hour during off peak periods.

iii. Starting Response. Starting response of vehicles at two phase and lead phase split timed signals were recorded. The recorder timed, with a stopwatch, the time interval between the time the signals turn green until the various vehicles in the queue facing the signal start to move. These observations were also made during two hours of both morning and afternoon peak periods plus one hour during off peak movements.

CHAPTER V

ANALYSIS OF DATA

The basis of this investigation is the hypothesis that:

1. Split phase traffic signals present less delay to motorists using an intersection than a three phase signal would and present an equivalent or greater vehicular capacity.

2. Split phase traffic signals present greater capacity to motorists using a high volume left turn intersection than a two phase signal would and present little or no greater vehicular delay to vehicles using the intersection.

3. Split phase traffic signals do not present a significantly more hazardous operation than a two or three phase operation would.

It is the intention of this study to closely scrutinize the operational characteristics of split phase traffic signals.

The reviews for this study fall into two broad categories namely:

1. Volume, Delay and Intersections Characteristics.

2. Accident or Safety record of converted intersections.

The final objective of the study is to present guidelines or warrants for the installation of left turn phases at signalized intersections.

I. VOLUME DELAY AND CHARACTERISTICS

A. THEORETICAL REVIEW:

Utilizing existing accepted methods of intersection timing design and capacity analysis the difference in cycle length requirements and capacity of various signal operations can be shown.

Two existing City of Edmonton intersections were analyzed. The recorded movements were utilized and:

1. Signal timing for 2, 2½, and 3 phase operations were calculated.

2. Intersection capacities and level of service were determined for the three phasing methods.

The method of calculation utilized was:

1. Signal Timing

The "Uniform Traffic Control Devices Manual for Canada" (1) method of determining phase timing was utilized. This method is based on an empirical formula whereby the traffic from any one direction of approach is reduced to an equivalent hourly volume per lane. The formula is:

$$Ve = \frac{(V + 0.5\ H + 0.6\ L)}{N}$$

where;

Ve = equivalent hourly volume

V = total approach volume

H = the number of trucks or heavy vehicles

L = the number of left turning vehicles

N = the number of lanes available

The heaviest equivalent approach volume for each phase is plotted against the sum of the heavy equivalent volumes of other phases in the intersection. This is conveniently presented in tabular form in The Uniform Manual,(1). The theory

of this method is that each vehicle passing through an intersection requires 2.1 seconds, with heavy vehicles taking 1.5 times as much time and left turns taking 1.6 times as much time. This method yields high cycle lengths. In practice it has been found that this method of design fails when the sum of volumes on other cycles lies in the range 700 - 1000 vehicles per hour and the phase being designed lies at or beyond 500 vehicles per hour. When this occurs the designer must rely on balancing volumes and capacities to determine timing.

2. Signal Capacities.

The capacity of the intersections were calculated utilizing The Capacity Manual (6) and the capacity nomographs as prepared by J. E. Leisch (13). The manual allows consideration of:

i. Street width

ii. Commercial Vehicles

iii. Parking restrictions

iv. Right Turns

v. Left Turns

vi. Peak hour factor based on metropolition

vii. Percentage green time (G/C)

viii. Bus stops.

The nomographs allow a graphical solution to capacity problems and present the Level C or design capacity of the intersections being analyzed.

The intersections analyzed represent typical city signaling situations. The 82 St. - 115 Ave. intersection is a typical outlying or residential area signal. The left turn phase installed at this location was primarily to attract a left turn movement to a newly constructed facility. The 103A Ave. - 97 St. intersection is a central area signal with high volumes through the entire day and a particularily high concentrated peak volume. TABLE I presents the parameters utilized in the intersection calculations.

For ease of calculation and since this is a theoretical analysis, the percentage of commercial vehicles was assumed to be 0%.

TABLE I

CAPACITY CALCULATION DATA

	82 St. - 115 Ave.				97 St. - 103A Ave.			
Direction of Approach	N	S	E	W	N	S	E	W
Through Volume	560	286	293	124	459	396	694	413
Vehicles per Hour (PM Peak)								
Left Volume VPH	0	144	150	69	0	0	249	0
Right Volume VPH	99	13	13	80	43	221	43	33
Total Volume VPH	659	443	456	273	502	617	966	446
Width (feet)	25'	25'	25'	25'	25'	25'	25'	25'
Percent Trucks (Used)	0%	0%	0%	0%	0%	0%	0%	0%

The results of this theoretical calculation are shown in TABLE II (actual calculations are in Appendix A).

TABLE II

2, 2½ and 3 phase

TIMING AND CAPACITY COMPARISON

	Dir.	Total from Table I	2 ph.	2½ ph.	3 ph.	Total from Table I	2 ph.	2½ ph.	3 ph.
Cycle Length (seconds)			48	65	72		60	80	92
Design cap. VPH	N	659	880	880	780	502	850	810	750
	S	443	880	1000*	750	617	850	810	750
	E	456	930	720	650	966	940	1300*	980
	W	273	930	720	650	446	1100	820	740

*Left turn phase plus through phase capacity.

82 St. - 115 Ave.

This particular intersection indicates a typical new signal installation situation. The ideal vehicular timing that should be installed cannot be used because of minimum timing requirements to safely handle pedestrian crossing. It also displays the familiar situation that a three phase signal could be installed and still provide adequate capacity for the present, leaving the ultimate

capacity problem to be handled at some point in the future when volumes increase beyond the capacity of a three phase signal. The removal of three phase signal has met with resistance from the motoring public and their installation should be carefully revised to avoid such a situation arising.

The data presented does show the relative differences in cycle length and capacity between the 2, 2½, and 3 phase signals.

It must be pointed out that the flash phase at this particular location was installed to attract a left turn for southbound vehicles, and this movement is $\left(\frac{144}{560} \times 100\right)$ 22% of the opposing through traffic.

97 St. - 103A Ave.

This intersection presently operates with a lead green flash phase, a 2 second clearance between the flash and steady green phase, and the pedestrian "walk" phase across the flash left movement is delayed 6 seconds after the end of the flash sequence.

The intersection is on the central area fringe. As such it is subject to high concentrated loads and certainly during peak periods the volumes are high enough that the intersection

operates in a Level E service (Explained on page 51). The narrow Eastbound width is such that the 2 phase operation coupled with the high opposing through volume would allow left turns on the amber phase only. The left turn phase for Eastbound traffic is $(\frac{249}{413} \times 100)$ 56% of the opposing through traffic.

This intersection was originally operated as a three phase signal. The extreme delay at the intersection prompted its reduction in phasing to a 2½ phase signal.

B. FIELD OBSERVATIONS:

Traffic studies in the past have almost exclusively dealt with empirical formulas developed through field observations. The advent of the computer has allowed simulation of intersection operation. This study is limited to actual field observations. Some comparison will be made to simulation studies where possible.

The City of Edmonton has recently been forced into improving many intersections to reduce delays. These improvements involved both the addition of turning phases and the reduction of three phase signals to 2½ phase signals.

At the time of this report the City of Edmonton had 22 flash phase signals. Of these:

3 were converted from 2 phase to 2½ phase lead

3 were converted from 2 phase to 2½ phase extended green

4 were converted from 3 phase to 2½ phase lead

3 were converted from 3 phase to 2½ phase extended green

5 were initially installed with lead phase

1 was initially installed with extended phase

3 were converted from a left turn arrow displayed after a through and right phase to a flashing extended phase

1. <u>BEFORE AND AFTER REVIEW</u>

Before and after data for 10 intersections were available. and are presented in TABLE III.

The before and after data were not obtained for this study but rather is data that were on record with the City of Edmonton Traffic Section.

Their method of collecting data was to send a counting team of four men to count all vehicle movements within the intersection, and to sample delays and cycle lengths. Counts are recorded in 15 minute intervals during the periods:

7 - 9 AM

10 - 10:30 AM

3 - 3:30 PM

4 - 6 PM

TABLE III

BEFORE AND AFTER COMPARISON

Intersection	Movement	7-9AM	10-10:30	3-3:30	4-6	7-9AM	10-10:30	3-3:30	4-6
156 St - 111 Ave.		No Signal				Lag Flash WBD			
	Left	122	56	64	368	123	42	78	443
	Through	256	107	148	267	314	87	142	365
	Opposing	240	128	80	481	285	88	129	461
	Delay(Sec)	-	-	-	75sec.	15.6	21	18.2	50.7
82 St. - 115 Ave.		2 Phase				2½ Phase Extended phase Southbound			
	Left	104	54	32	144	170	32	49	193
	Through	455	169	136	286	433	110	117	269
	Opposing	340	133	185	560	264	101	179	592
	Delay	18	16	16.5	28.0	21.8	19.5	25.7	30.4
97 St. - 108 Ave.		No Signal				2½ Phase Lead Phase Northbound			
	Left	99	20	27	117	82	29	25	101
	Through	288	159	163	785	317	127	218	847
	Opposing	618	174	170	469	611	189	228	458
	Delay	-	-	-	-	-	-	-	-

TABLE III (Cont)

Intersection	Movement	7-9AM	10-10:30	3-3:30	4-6	7-9AM	10-10:30	3-3:30	4-6
127 St. - 125 Ave.		Two Phase				2½ Phase Extended Phase (double left)			
	Left	360	110	100	591	429	110	129	703
	Through	180	17	25	45	179	20	26	66
	Opposing	113	47	52	443	133	52	77	529
	Delay	45.5	20	18	61	23.5	17	18	46
116 St. - 100 Ave.		Three Phase				2½ Phase Extended Phase Eastbound			
	Left	352	46	67	323	429	55	79	343
	Through	212	16	30	106	354	39	56	183
	Opposing	351	150	236	908	561	188	196	799
	Delay	28.1	26	32	126	34	26.2	24.8	108
118 Ave. - 127 St.		Three Phase				2½ Phase Extended Phase Southbound			
	Left	394	68	80	198	470	106	106	277
	Through	280	39	43	123	292	43	52	160
	Opposing	137	13	43	292	147	18	56	386
	Delay	42	28	34	28	39.8	28.1	25.8	27.2
142 St.-Stony Plain Rd.		Three Phase				2½ Phase extended phase & double left Westbound			
	Left	123	48	137	68.5	65	69	143	596
	Through	325	104	220	629	323	167	269	805
	Opposing	907	148	192	291	887	216	217	425
	Delay	62	28.2	32	180 (up to 6 min.)	32.6	12.5	23.4	41.2

TABLE III (Cont)

Intersection	Movement	7-9AM	10-10:30	3-3:30	4-6	7-9AM	10-10:30	3-3:30	4-6
97 St. - 103A Ave.		Three Phase				2½ Phase Lead Phase Eastbound			
	Left	124	46	59	249	115	44	84	280
	Through	307	110	124	694	230	95	185	694
	Opposing	639	125	139	413	764	135	142	515
	Delay	38	27	31	54	23.9	21.7	21.1	48.4
163 St. - Stony Plain Rd.		No Signal				2½ Phase Lead Phase Westbound			
	Left	104	25	21	116	60	24	32	105
	Through	129	56	69	176	202	106	161	364
	Opposing	102	57	56	193	195	90	126	381
	Delay	-	-	-	71	21.9	20.0	11.0	24.2
91 St. - 82 Ave.		Special left turn phase Eastbound				2½ Phase extended phase Eastbound			
	Left	77	23	54	172	61	33	41	153
	Through	439	150	284	1066	500	195	317	981
	Opposing	727	159	207	453	731	236	338	795
	Delay	25.9	25.9	29.1	39.8	22.7	16.6	18.2	32.9

These counts are then reviewed to determine the peak hour volumes. These peak volumes are then recorded on cardex cards, maintained as such until replaced by an updated count. The old cards are photocopied and filed for future use.

The general nature of this data does not allow an intense mathematical review of the individual intersections, but it is felt that enough evidence is available to indicate that the flash phasing has allowed a general increase in left turn volume, and a reduction in overall intersection delay.

When comparing intersections under which two phase signals were converted to 2½ phase signals, the major points revealed were:

1. The increase in delay during off peak periods.
2. The increase in left turns during peak periods.

This is due to the increased cycle length after the phase change and the allowance of the free left during each cycle.

When comparing three phase signals, which have been converted, the observations of interest are:

1. The decrease in delay time.

2. The fact that left turn volumes are not reduced.

These observations indicate the saving of time presented by the signal and the maintenance of high capacities in the heavy left turn direction. This compares favorably to the theoretical calculation discussed previously.

2. LEVEL OF SERVICE REVIEW

The level of service of 20 intersections was determined by Homs (12) and is presented in TABLE IV. This data allows a comparison of the loading of the various intersections and is utilized in various portions of this study.

Level of Service is described in The Highway Capacity Manual (6) as, "Level of service is a qualitative measure of the effect of speed and travel time, traffic interruptions or restrictions, freedom to maneouver, safety, driving comfort and convenience, and economy. Travel speed is the major factor used in identifying the level of service with ratio of service volume to capacity (V/C ratio) being used as a second accompanying factor."

Levels are:

Level A -free flow with low volumes and high speed.

Level B -zone of stable flow with operating speeds

TABLE IV

LEVEL OF SERVICE BY HOMS ANALYSIS

Location	Left Volume	G/C Left	% Trucks	Level of Service
111 Ave. - 142 St.	140	.30	5	A-C
107 Ave. - 149 St.	235	.30	5	A-C
103A Ave. - 97 St.	225	.20	5	E
101 Ave. - 163 St.	120	.20	5	A-C
111 Ave. - 156 St.	355	.20	5	E+
115 Ave. - 82 St.	165	.20	5	A-C
118 Ave. - 127 St. (2 phase)	400	.40	5	D
101 Ave. - 142 St. (% lane)	550 (double)	.35	0	E
116 St. - 100 Ave.	429	.20	0	E
127 St. - 125 Ave.	703	.40	5	E
75 St. - Argyll	487	.30	5	E
97 St. - 108 Ave.	117	.20	5	A - C
97 St. - 118 Ave.	306	.35	5	D
109 St. - 102 Ave.	250	.20	0	E
103 St. - 104 Ave.	128	.20	5	A - C
Jasp. - 97 St.	180	.20	0	D
95 St. - 118 Ave.	115	.20	5	A-C
109 St. - 100 Ave.	115	.20	0	A-C
Jasp. - 109 St.	122	.20	0	A-C

beginning to be restricted.

Level C -is still stable flow but speeds and maneuverability more closely controlled.

Level D -approaches unstable flow with tolerable operating speeds.

Level E -cannot be described by speed alone. Volumes are near capacity level.

Level F -forced flow at low speeds where volumes are below capacity.

3. ADVANCE FLASH MOVEMENT OBSERVATIONS

During the first months of flash phase operation, reviews were made of lead flash installation to determine the usage of flash phases. Seven intersections were observed for ½ hour periods during the morning and peak periods. The observers recorded all left turn movements occurring in the direction of the flash phase specifying whether the turn occurred during the flash phase, the interval during which a green is displayed to the advance movement and not the opposing traffic or during the steady green phase. The results of these observations are shown on TABLE V.

TABLE V

LEFT TURN OBSERVATIONS

Intersection	Time	Fl.Gr.	Fl. Cl.	Left Turns Green	Date
104 Ave.-103 St.	8-8:30	20	2	48	March 5
	5-5:30	16	2	19	
	8-8:30	23	2	35	March 12
	5-5:30	7	0	17	
108A Ave.-97St.	8-8:30	47	2	25	March 5
	5-5:30	19	3	20	
	8-8:30	49	0	27	March 12
	5-5:30	15	2	20	
109 St.-Jasper Ave.	8-8:30	92	10	105	March 5
	5-5:30	58	7	25	
	8-8:30	73	5	134	March 12
	5-5:30	52	6	26	
101 St.-104 Ave.	8-8:30	179	9	61	March 1
	5-5:30	161	7	33	
109 St. - 100 Ave.	8-8:30	33	0	25	March 5
	5-5:30	34	0	33	
	8-8:30	37	0	21	March 12
	5-5:30	32	1	36	
103A Ave.-97St.	8-8:30	77	9	26	March 1
	5-5:30	106	11	23	
97 St.-Jasper Ave.	8-8:30	15	0	65	March 1
	5-5:30	18	1	67	

The data obtained from ½ hour studies was primarily to record use made of flashing phases, the clearance period and the steady green phase. All signals observed are of the lead type.

This data, as does other data in this report, points out the shift in the majority of turns from the steady green phase to the flash phase during periods of congestion. This is particularly evident in the 103A Ave. - 97 St. and 104 Ave. - 101st St. data.

Similarily high volume turns appear to be forced into utilization of the clearance phase during high volume periods. Remarks of the observers suggest that most drivers realized they were turning on the clearance phase.

C. FIELD STUDIES:

1. Left Turn Movements

The first study was simply an observation of the split phase operation. For this study the observer watched the left turn movements during peak and off peak periods recording:

I Lead Phases - left turns on

1. flash green phase
2. steady green clearance phase

3. both direction green

4. yellow phase

5. red indication

II Extended Phases - left turns on

1. Green phase - jumped the gun

   i.e. quick start across opposing queue

2. both direction green

3. green clearance (yellow to opposing traffic, steady green to left turning traffic)

4. flashing green

5. yellow phase

6. red indication

The results of this study are presented in TABLE VI.

TABLE VI

LEFT TURN OBSERVATIONS

Intersection	Obser.Hrs.	J.T.G. No.	J.T.G. %	Gr. Cl. No.	Gr. Cl. %	Green No.	Green %	Gr.Cl. No.	Gr.Cl. %	Fl.Gr. No.	Fl.Gr. %	Amber No.	Amber %	Red No.	Red %	Total
A. 2 Phase Signal																
109St.-107Ave.	2	0	0		-	86	78		-		-	17	15	8	7	111
	½	0	0		-	21	95		-		-	0	0	1	5	22
	½	0	0		-	22	82		-		-	4	15	1	3	27
	2	0	0		-	39	46		-		-	18	21	27	32	84
	2	0	0		-	47	49		-		-	31	32	18	19	96
	½	0	0		-	22	76		-		-	5	17	2	7	29
	½	0	0		-	30	65		-		-	13	28	3	7	46
	2	1	1		-	127	65		-		-	50	25	29	10	97
	2	0	0		-	71	68		-		-	25	24	9	8	105
	½	0	0		-	14	88		-		-	2	12	-		16
	½	1	1		-	17	60		-		-	10	40	-		28
	2	1	1		-	26	25		-		-	46	45	29	30	102
	2	1	1		-	62	67		-		-	28	26	17	16	108
	½	0	0		-	14	87		-		-	1	12	1	12	16
	½	0	0		-	19	76		-		-	5	20	1	4	25
	2	0	0		-	33	69		-		-	14	29	1	5	48

TABLE VI (Cont)

Intersection	Obser.Hrs.	J.T.G. No.	J.T.G. %	Gr. Cl. No.	Gr. Cl. %	Green No.	Green %	Gr. Cl. No.	Gr. Cl. %	Fl. Gr. No.	Fl. Gr. %	Amber No.	Amber %	Red No.	Red %	Total
B. 2½ Phase Advance Signal																
163 St. - Stony Plain Rd.																
	2	-		-		58	51	-		45	40	5	4	5	4	113
	½	-		-		12	50	-		9	38	1	4	2	8	24
	½	-		-		7	23	-		20	66	1	3	2	6	30
	2	-		5	2	6	27	-		141	57	21	8	12	5	246
97 St. - 103A Ave.																
	2	-		10	6	39	22	-		120	69	16	9	10	6	175
	½	-		2	4	19	43	-		17	40	4	8	2	4	44
	½	-		3	4	27	32	-		42	50	9	11	3	4	84
	2	-		57	12	88	19	-		234	51	46	10	31	7	456
C. 2½ Phase Extended Signal																
142 St. - Stony Plain Rd.																
	2	1	1	-		40	24	0	0	128	76	-		-		169
	½	0	0	-		31	45	0	0	36	52	2	3	0	0	69
	½	0	0	-		35	24	0	0	101	71	6	4	1	0	143
	2	0	0	-		135	12	0	0	889	80	68	6	15	1	1107
127 St. - 118 Ave.																
	2	0	0	-		178	22	45	6	554	68	28	3	3	0	808
	½	0	0	-		36	33	8	6	62	60	1	1	0	0	107
	½	0	0	-		37	34	10	8	59	58	0	0	0	0	106
	2	0	0	-		170	30	57	10	333	59	4	1	1	0	565

TABLE VI (Cont)

Intersection	Obser.Hrs.	J.T.G.		Gr. Cl.		Green		Gr. Cl.		Fl. Gr.		Amber		Red		Total
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
82 St. - 115 Ave.																
	2	0	0	-		75	28	18	7	159	60	13	5	0	0	265
	½	0	0	-		10	31	1	3	21	66	0	0	0	0	32
	½	1	2	-		21	43	2	4	25	51	0	0	0	0	49
	2	1	0	-		48	14	9	3	258	77	16	5	0	0	332
156 St. - 111 Ave.																
	2	0	0	-		141	64	0	0	71	33	4	2	5	2	221
	½	0	0	-		30	71	0	0	11	26	1	2	0	0	42
	½	0	0	-		39	50	0	0	31	40	6	12	2	1	78
	2	0	0	-		239	33	0	0	411	57	48	6	26	4	724
Opposing Left Not Banned																
	2	1	1	-		93	80	-		-		11	9	2	1	117
	½	0	0	-		18	90	-		-		2	10	0	0	20
	½	0	0	-		26	97	-		-		0	0	1	3	27
	2	1	1	-		71	91	-		-		2	3	4	6	78

DISCUSSION OF INTERSECTION OBSERVATIONS

A. TWO PHASE OPERATION:

The most obvious observation of two phase left turning movements is the percentage decrease in left turns taking place during high volume operation and, probably more importantly the percentage of left turn movements taking place during the amber and red phases of the cycle in high volume periods.

These observations bring B. W. McKay's (5) observation into focus. Namely: that if an average of two or more turns take place during yellow and red phases, a special phase is required. The 109 St. - 107 Ave. cycle length averaged 97 seconds during the peak periods as 26 cycles per hour suggesting that none of the directions considered indicate a left turn phase is necessary. However, on reviewing the fifteen minute breakdown of the counts, the westbound left averaged 17/6.5 = 2.5 turns during the period from 5 - 5:15 PM. The northbound averaged a similar rate during the periods 8 - 8:15 AM and 5 - 5:15 PM. This could indicate the possibility that volumes are such that a left turn phase may soon be warranted.

One other point is the reluctance of drivers in this intersection to jump the gun on left turns. This is probably due to the generous geometry of this intersection.

B. TWO AND ONE HALF PHASE EXTENDED GREEN OPERATION:

This data clearly indicates the main advantage of the split phases, namely the full utilization of the full green phase in the absence of opposing direction traffic. With little opposing traffic the percentage of left turns on the full green went as high as 71%. It is the authors opinion that this figure could be as high as 100%, except for the random arrival of vehicles. This suggests that during off-peak hours, the lag flash could be dropped from the cycle.

The utilization of amber and red portions of the phase cannot be eliminated, but their use again can be used as a barometer to gauge the volume handling adequacy of the signal.

Of interest in this data is the information presented for the Eastbound left turn at 156 St. - 111 Ave. This is the movement opposite an extended left turn and in this case was not banned. The left turns on amber and red are across the path of vehicles facing a green. And they were invariably

described as dangerous by the observers.

C. TWO AND ONE HALF PHASE LEAD GREEN OPERATION

Here again, the advantage of utilizing the entire green portions of the phasing is noticed, with as high as 51% of the turns taking place on the steady green. The shift to reliance on the flash phase as opposing volumes build up is also noted.

This operation would not lend itself to the removal of the flash phase during off peak hours as many motorists, obviously familiar with the intersection, utilize a very quick start on the flash to make their turn.

The utilization of the clearance phase draws attention to this portion of cycle. The observers noticed that this clearance period should be designed to allow the last vehicle to turn prior to the start of the opposing column and that if a vehicle stops at the loss of the flash and has enough time to start prior to the opposing traffic starting, a dangerous situation arises. Based on this observation, the City has timed the clearance period considering the starting response of the opposing queue. As determined later, the starting response is approximately

2 sec., therefore the clearance period should be only 2 seconds if a second clearance is required.

2. Left Turn Delay Study

The second study carried out was to determine left turn delays. For this study, two field observers were required and depending on the type of intersection (i.e. one direction left turns banned or not). The observers each carried out two operations. These were:

i. Every tenth vehicle was timed by stop watch from time of arrival in signal queue to exit from the intersection.

This was initially based on every fifteenth vehicle, but was reduced to every tenth on the first day of observation. Several signals involved had a cycle capacity of approximately 15 vehicles per cycle. Due to this, it was felt that biased readings were resulting. For example, for four cycle readings in a row, the fifteenth vehicle was the third vehicle from the stop line.

ii. To count all through, left and right turn movements from the direction he was observing.

In addition to the above, sample cycle lengths were taken every five minutes.

TABLE VII

INTERSECTION DELAY & VOLUMES

Direction	Time	Approach Vol. Left	Approach Vol. Through	Opposing Through	Total Phase Vol.	Av. Cycle (sec.)	Av. Delay (sec.)
2 PHASE SIGNAL							
109 St. - 107 Ave.							
Eastbound	7 - 9	105	1131	816	2052	89	55
	9:30 - 10	16	194	107	317	65	33
	3 - 3:30	28	208	243	479	68	46
	4 - 6	102	1069	1341	2512	97	78
Westbound	7 - 9	98	816	1131	2045	89	82
	9:30 - 10	16	107	194	317	65	75
	3 - 3:30	25	243	208	476	68	22
	4 - 6	48	1341	1069	2458	97	62
Northbound	7 - 9	106	940	1295	2341	89	48
	9:30 - 10	29	177	246	452	65	22
	3 - 3:30	45	222	312	579	68	39
	4 - 6	206	1344	1093	2643	97	102
Southbound	7 - 9	111	1295	940	2346	89	53
	9:30 - 10	22	246	177	445	65	17
	3 - 3:30	27	312	222	561	68	19
	4 - 6	84	1093	1344	2521	97	52

TABLE VII (cont)

Direction	Time	Approach Vol. Left	Approach Vol. Through	Opposing Through	Total Phase Vol.	Av. Cycle (sec.)	Av. Delay (sec.)
2½ PHASE LEAD SIGNAL							
163 St. - Stony Plain Rd.							
Westbound	7 - 9	113	313	336	762	99	21.9
	9:30 - 10	24	90	106	220	76.2	20
	3 - 3:30	31	126	161	318	48	11
	4 - 6	241	660	671	1572	99	24.2
97 St. - 103A Ave.							
Eastbound	7 - 9	195	445	1151	1791	80	23.9
	9:30 - 10	44	95	135	274	75	21
	3 - 3:30	84	185	142	411	75	21.1
	4 - 6	456	1117	843	2416	80	48.4
2½ PHASE EXTENDED SIGNAL (DOUBLE LEFT)							
142 St. - Stony Plain Rd.							
Westbound	7 - 9	168	541	1416	2125	102	32.6
	9:30 - 10	69	167	217	453	85	12.5
	3 - 3:30	143	269	216	628	80	23.4
	4 - 6	1107	1363	796	3266	119	41.2

TABLE VII (Cont)

Direction	Time	Approach Vol. Left	Approach Vol. Through	Opposing Through	Total Phase Vol.	Av. Cycle (sec.)	Av. Delay (sec.)
2½ PHASE EXTENDED SIGNAL							
Southbound	7 - 9	808	427	197	1432	103	39.8
	9:30 - 10	106	43	18	167	103	28.1
	3 - 3:30	106	52	56	214	98	25.8
	4 - 6	565	263	555	1383	108	27.2
82 St. - 115 Ave. Southbound	7 - 9	265	726	478	1469	73	21.8
	9:30 - 10	32	110	101	243	66	19.5
	3 - 3:30	48	117	179	344	74	25.7
	4 - 6	331	475	1035	1841	75	30.4
156 St. - 111 Ave. Westbound	7 - 9	221	587	484	1292	100	15.6
	9:30 - 10	42	87	88	217	48	21
	3 - 3:30	78	142	129	349	50	18.2
	4 - 6	719	665	820	2204	100	50.7
Eastbound							
OPPOSING FLASH TURN	7 - 9	107	484	587	1178	100	21.9
	9:30 - 10	20	88	87	195	48	11
	3 - 3:30	27	129	142	298	50	24
	4 - 6	78	820	665	1563	100	27

TABLE VII (Cont)

Direction	Time	Approach Vol. Left	Approach Vol. Through	Opposing Through	Total Phase Vol.	Av. Cycle (sec)	Av. Delay (sec)
3 PHASE SIGNALS							
107 Ave. - 149 St. Westbound	3 - 3:30	112	156	126	394	85	28
	4 - 6	475	550	549	1024	120	33
111 Ave. - 142 St. Westbound	7 - 9	116	651	698	1467	99	25
	10 - 10:30	22	126	164	312	88	34
	3 - 3:30	85	203	139	427	90	28
	4 - 6	370	1119	822	2311	111	44
Southbound	7 - 9	92	367	653	1112	99	37
	10 - 10:30	50	59	62	171	88	18
	3 - 3:30	41	104	101	246	90	57
	4 - 6	280	704	360	1344	111	136

DISCUSSION OF INTERSECTION DELAY

The delays observed in the left turning lanes at studied intersections reveal the following:

A. TWO PHASE INTERSECTION

The obtained data for a two phase intersection indicate that the number of left turning vehicles remain fairly consistent through peak and off peak hours. The delays recorded indicate that the left turning delay in 2 phase signals varies directly with the cycle length and the intersection volume. This would indicate that, as reported by others, the cycle length is the key to intersection delay.

The results for this study were obtained during a one day count. The short period of observation in off peak hours makes the data subject to extreme variation by as few as one or two poor readings. The 107 Ave. - 109 St. WBD 9:30 - 10:00 AM reading includes data of a vehicle stalled through one cycle, thus giving an unusable average.

B. TWO AND ONE HALF PHASE EXTENDED SIGNALS

The two and one half phase signals indicate a similar relationship between delay and cycle length as the two phase signal. However, whereas the two phase average

delay is, for most cases, greater than 50% of the cycle length, in the $2\frac{1}{2}$ phase signals the average delay is in most cases less than 1/3 of the average cycle length.

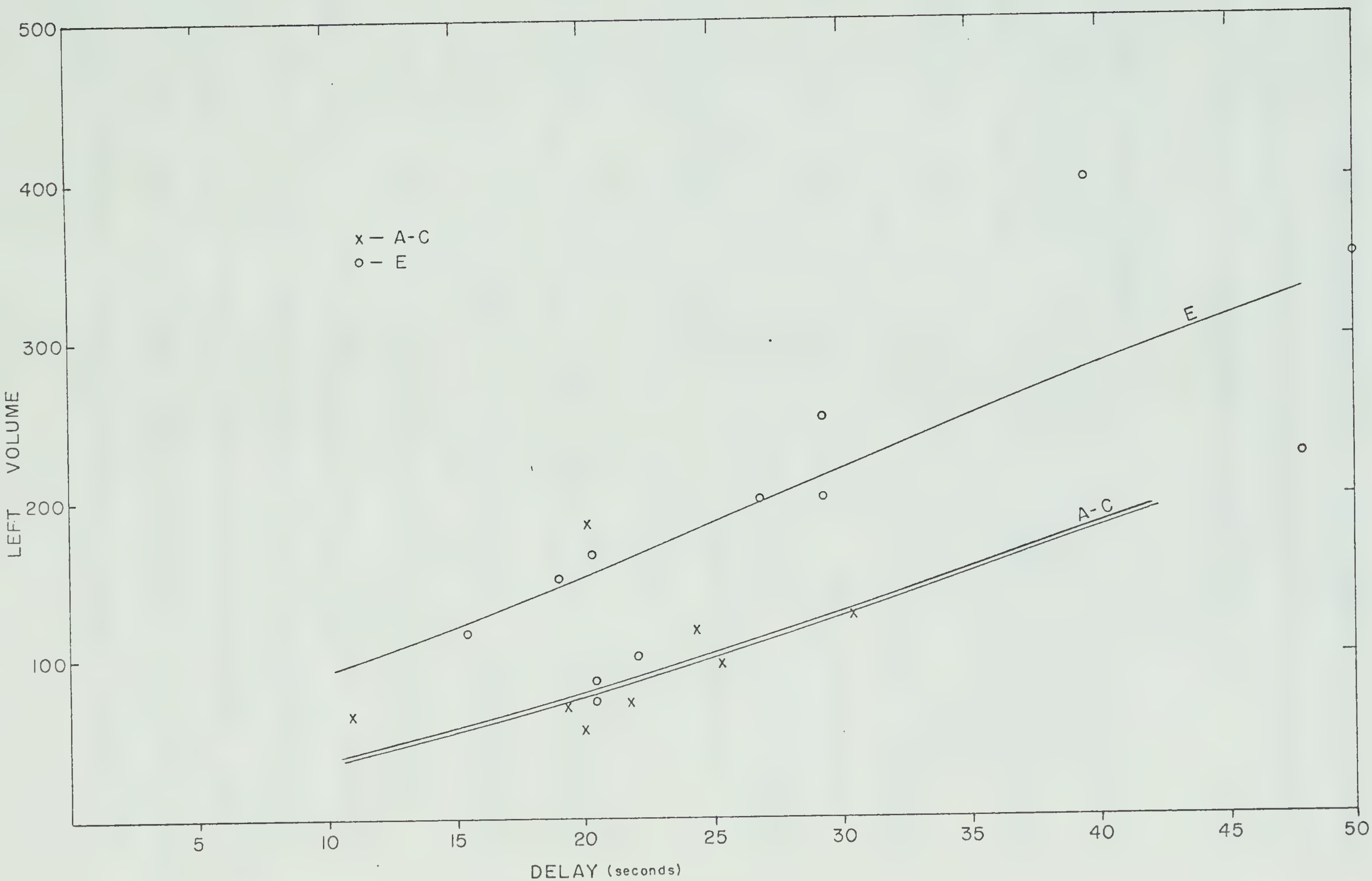
A review of the left turn volume expressed as a percent of the through volume points the obvious need for the special left turn consideration with the turn running as high as 46.5% of the through volume.

Of interest is the data obtained for 156 St. - 111 Ave. EBD traffic. This turn has no separate turn phase and presents an amber phase to turning traffic while opposing direction traffic has a green phase. The delay is low and reflects the high capacity volume ratio of the intersection.

C. TWO AND ONE HALF PHASE LEAD SIGNALS:

The lead phase signal shows similar delay characteristics to the extended phase signals. The one exception being the 103A Ave. - 97 St. PM average delay. This movement is over capacity and this is reflected in the average delay recorded.

Utilizing Hom's (11) analysis to determine level of service, a plot (FIGURE 10) of delay time based on volume and level of service is made. The effect of congestion



Level of Service Delay

Figure 10

is clearly evident and points out the desirability of providing the most efficient timing sequence hence the best design capacity to reduce delay experienced.

D. THREE PHASE SIGNALS:

The three phase data deals with the all movement phases of two signals and the phase which has an opposing movement for southbound traffic at 111 Ave. - 142St.

The all movement phases indicate a delay of approximately 1/3 the average cycle length. The significant point is that the left turn volume is low. When compared to similar volumes handled by a 2½ phase signal much less delay is incurred, by the split phase signal.

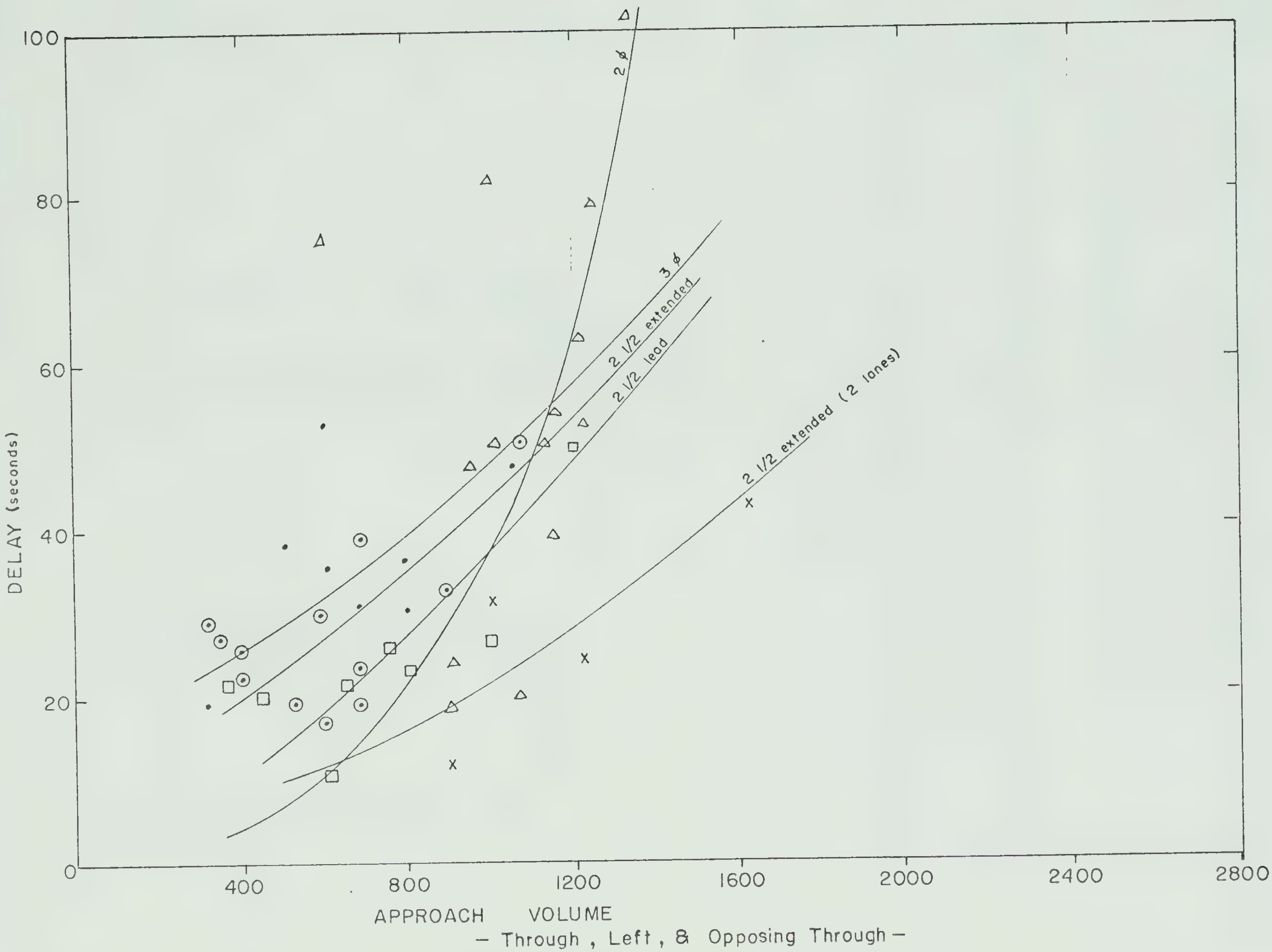
i.e.	82 St. - 115 Ave.	331 left turns - delay 30.4 sec.
vs.	111 Ave. - 149 St.	370 left turns - delay 44 sec.
	156 St. - 111 Ave.	78 left turns - delay 18.2 sec.
vs.	111 Ave. - 142 St.	85 left turns - delay 28 sec.

The two directional movements in the three phase signal shows a fluctuating condition wherein a low delay is recorded during off peak hours and an extremely high delay during peak hours. This indicates that the assured green time during off peak adequately handles through and turning movements but the peak hour through volumes are

high enough to pre-empt the turning movement. The green to cycle ratio is low and creates a peak hour capacity restriction.

A plot of left turn delay versus total phase approach volume (i.e. Approach through and left plus opposing through - see FIGURE 11) indicates that the left turn delay for a two phase signal crosses the single lane split phase and three phase delays in the range from 1000-1200 VPH total approach volume.

This is the range that the designer must consider the installation of a special left turn phase. Certainly if the geometry of the intersection is such that the through vehicle delay reflects the left turn delay, then a special left turn phase is warranted in this area.



Phasing Delay

Figure 11

3. Starting Response

The third study carried out was a review of starting response. Data was collected from two types of intersections.

1. An advance flash phase signal
2. A two phase signal.

The data obtained was compared to that collected by E. T. George Jr. and F. M. Heroy Jr.(11) and then to the time-space discharge data presented in the NCHRPR #32 (6).

The results of the starting response are shown in TABLE VIII.

TABLE VIII

STARTING RESPONSE

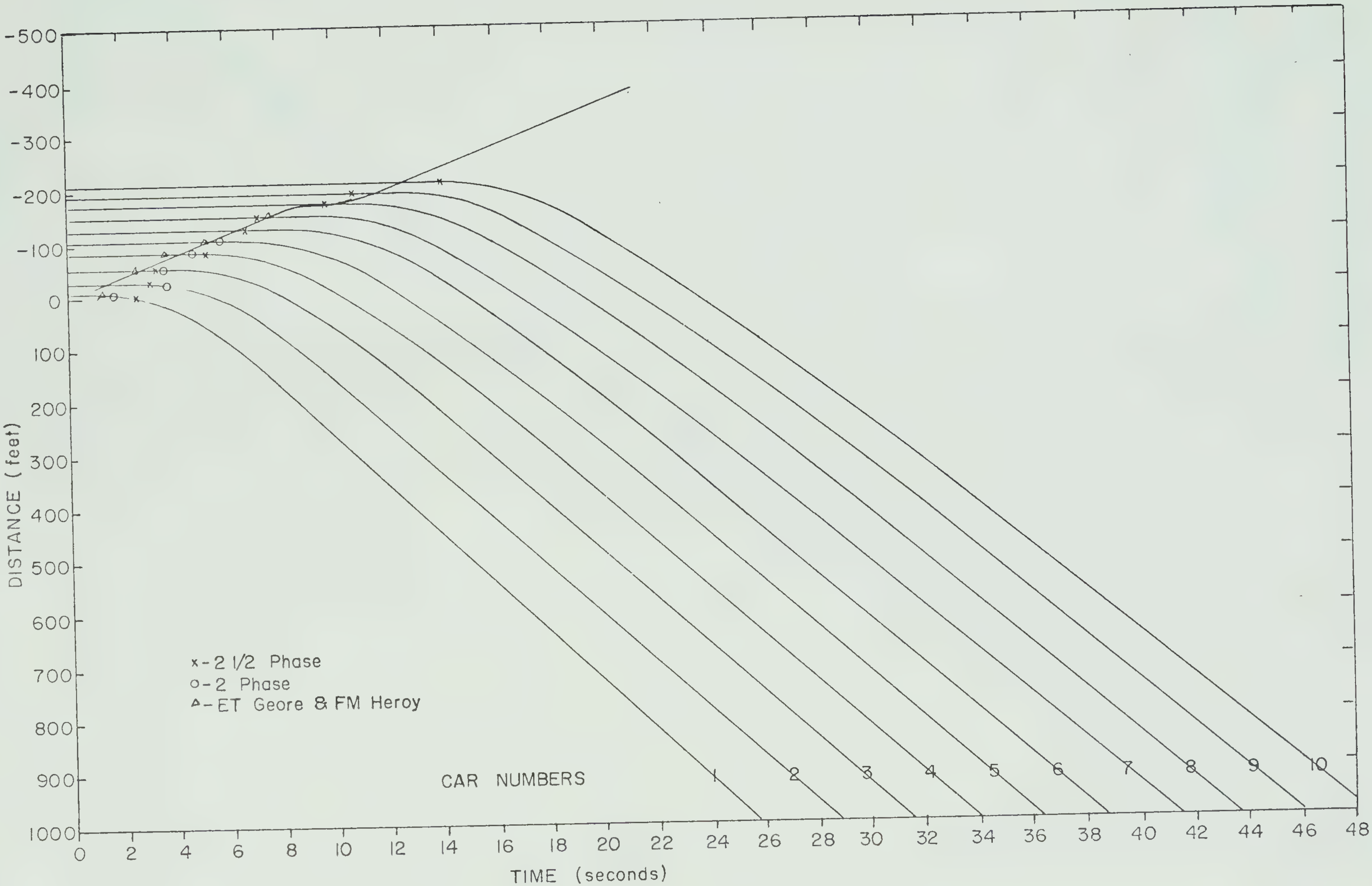
Vehicle	2 phase		2½ phase	
	(Sec)	n	(Sec)	n
1	1.9	31	1.8	42
2	2.8	34	3.2	39
3	3.5	26	4.1	43
4	4.9	20	4.4	27
5	5.4	14	4.8	21
6	6.8	7	5.8	12
7	7.0	4	8.1	6
8	9.4	5	10.7	4
9	10.8	4		
10	14	1		

n = number of observations

The starting response data was collected to see if a materially shorter starting time could be observed at a flashing green signal as was expected by observation. The second purpose for obtaining the data was to compare the data to the NCHRPR #32 (6) simulation discharge run. FIGURE 12.

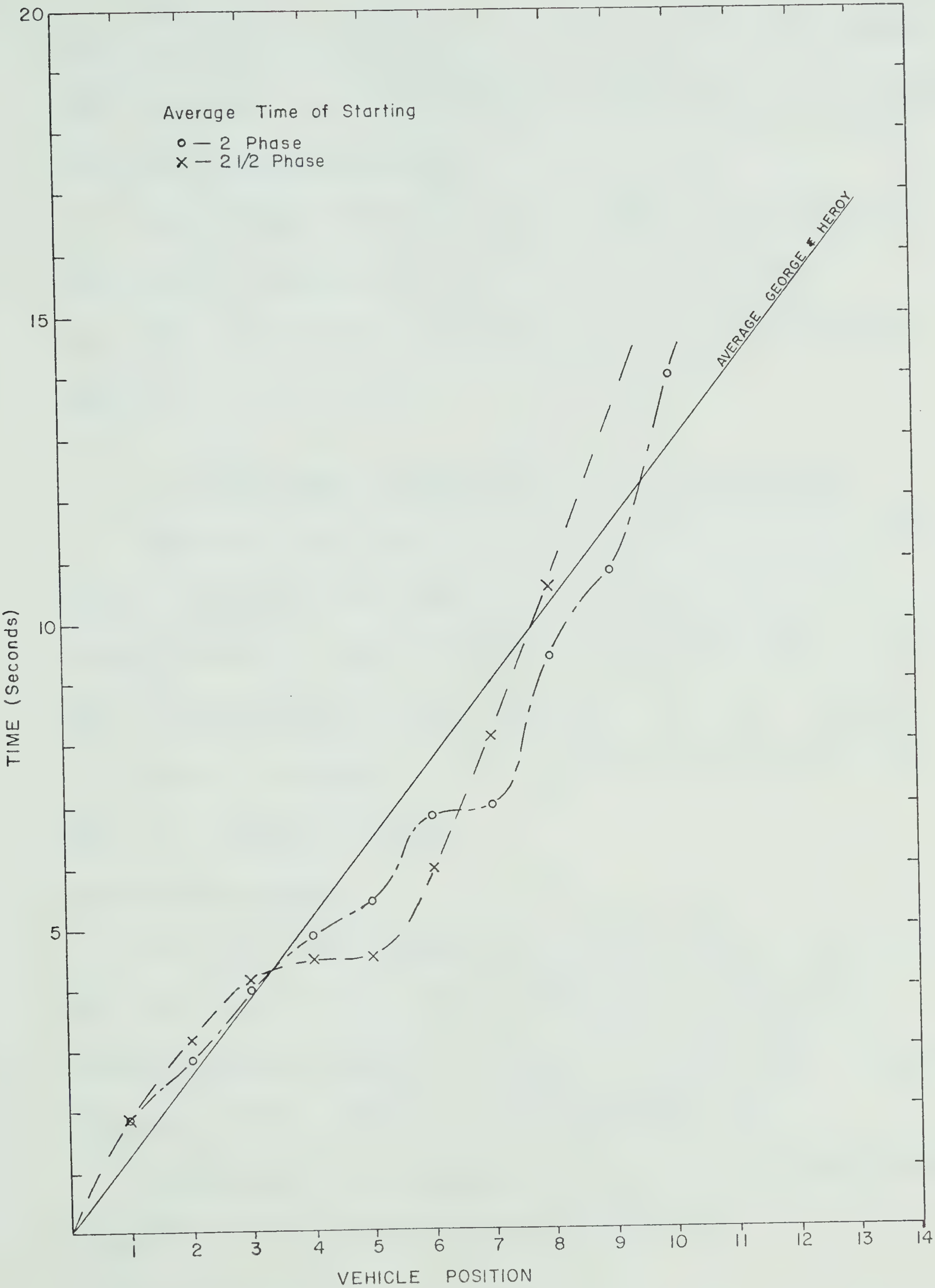
The data collected does not indicate a material difference in starting response between the two signal types (average response used) nor does it vary markedly from the Starting Response data of E. T. George Jr. and F. M. Heroy Jr.(11) as shown in the FIGURE 13 below, particularly for the first four vehicles

The one noticable difference between split phase and two phase starting response is the location of the knee or simultaneous starting point in the queue. The two phase data knee point occurs between the 6th and 7th vehicle as did George & Heroys'(11) FIGURE 2 & 3. The split phase differs in that the simultaneous start occurs between the fourth and fifth vehicle. This was particularly evident during peak hours. The drivers appeared to be more attentive and were anticipating the signal change.



Recorded Delay on Simulated Graph

Figure 12



Observed Ac. Starting Time

Figure 13

The comparison of the data to the simulation run indicates that the field starting response is somewhat ahead or quicker than the simulated procedure.

The starting response data utilized for this study was not as extensive as George & Heroys (11), but the 300 plus samples are large enough to cover random errors.

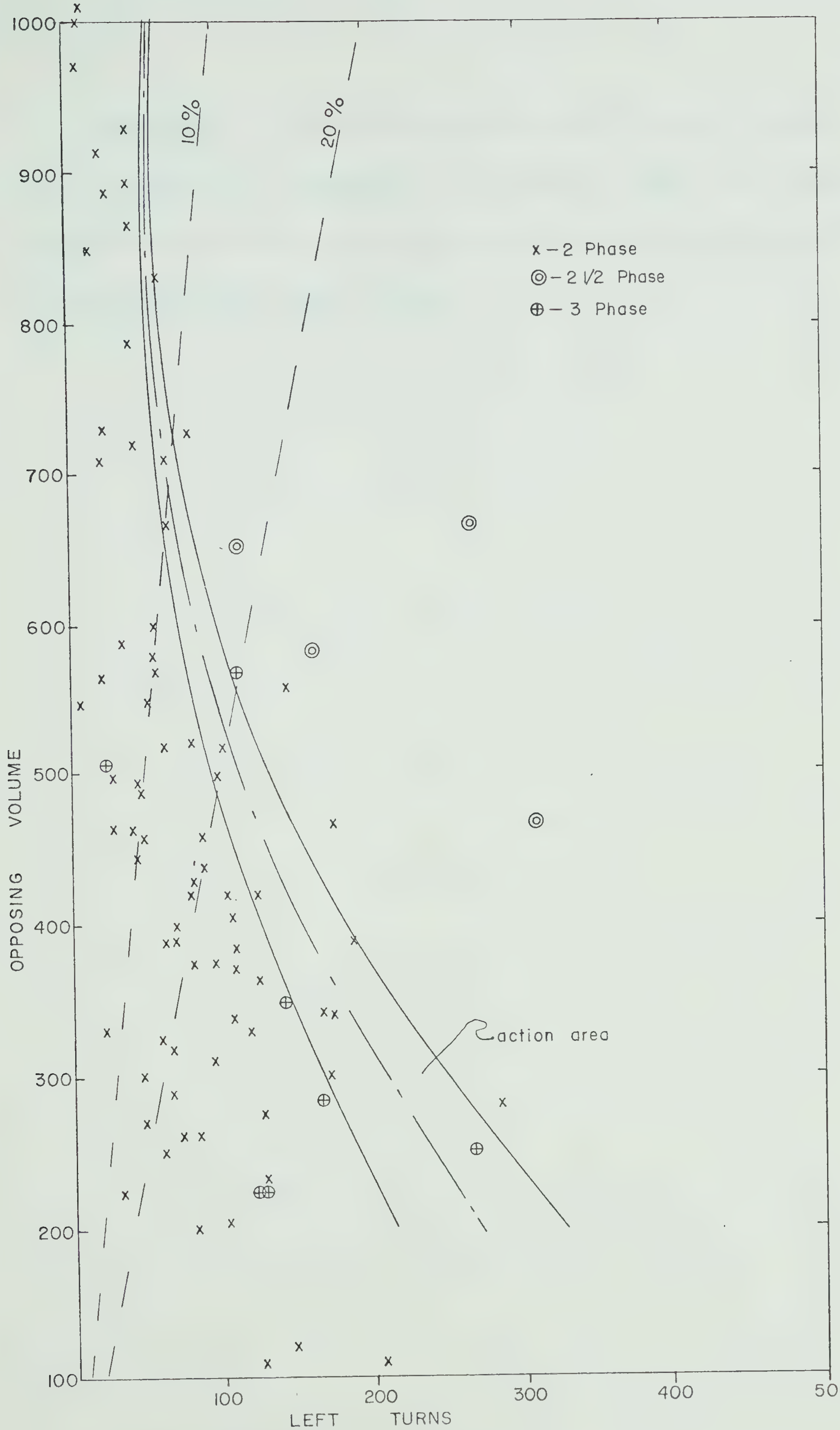
4. <u>Left Turn Volume Limits at 2 Phase Signals</u>.

The review of left turn volumes warranting left turn phases again utilized the City of Edmonton peak hour intersection counts. Only the opposing through volume and the left turning volumes were considered. The data utilized is listed in Appendix B. The results of this review are shown on FIGURE 14 below.

<u>Left Phase Warrant</u>

The left turn no opposing traffic plot for two phase and some multi phase signals indicates a rather well defined limit to allowable left turn volumes based on opposing through traffic. This is shown in FIGURE 14.

These data are primarily peak hour counts and as such reflect at least design capacity operation.



Two Phase Left Turn Volumes

Figure 14

The CGRA (1) standard of 10 & 20% of heavy volumes is, as expected, opposite to the actual left turn capacity at the extreme ends of the plot but rational in the 450 to 700 opposing volume range.

II. SAFETY

As stated in "Traffic Engineering" by Matsun Smith and Hurd, the objective of phasing is to accommodate all traffic movement with increased safety and minimum delay. The obvious question to be asked with regards to safety of lead and lag phases are:

1. Are split phase signals safer than two phase operation?

2. Are split phase signals safer than three phase operations?

3. Can an increase in accidents be expected when converting from a two or three phase signal operation to a split phase operation?

4. Which is safer - a lead or a lag split?

5. What effect does the split phase have on pedestrian safety?

6. What special precautions should be considered to make split phasing acceptable for motorists safety?

To answer these questions, traffic accident records for 26 intersections were reviewed. Of these, 11 were complete enough to procure before and after comparisons.

The accident records utilized are maintained by the Traffic Engineering Division of the City of Edmonton Engineering Department. The data for the accident records are obtained by the Edmonton City Police. The Police policy is to attend all accidents occuring in the city. The damage estimate is made by the officers investigating the occurrence. It is felt that the data reported for both the before and after data is comparable, with the only inequality being the inflationary trends of the time period.

Injury data is not considered in this study. Police reporting does not distinguish severity of injury accidents and a minor cut and major fractures appear only as an injury. Injuries recorded at split phase signals for 1968 and 1969 are shown in TABLE IX.

TABLE IX

INTERSECTION INJURIES INVOLVING LEFT TURNS

Location	1968 Injuries Left Turn	1968 Injuries Other	1969 Injuries Left Turn	1969 Injuries Other
142 St.-Stony Pl.Rd.*	-	-	2	3
97 St. - 103A Ave.	-	8	1	7
127 St. - 118 Ave.+	1	3	4	12
Jasper - 109 St.	4	34	-	28
109 St. - 100 Ave.	1	5	-	-
97 St. - Jasper Ave.	-	8	-	8
95 St. - 118 Ave.	-	8	-	3
101 St. - 103A Ave.	7	13	-	3
127 St. - 125 Ave.	-	4	3	7
97 St. - 118 Ave.	1	5	4	8
116 St. - 100 Ave.*	-	-	-	10

*Signal phasing installed Nov. 1968

+Signal phasing installed June 1968

One major problem encountered in the data review was the Traffic Engineers conversion from hand prepared accident cards to computer printed accident cards. This conversion took place at the beginning of 1968. The hand cards located all accidents at intersections, whereas the computer analysis distingui es the distance of occurrence from the intersection, thus eliminating mid block occurrences from the intersection total. Intense reviews were required to eliminate non intersection accident records from the pre 1968 data. The only remaining questionable data in the accident review is in the "Follow-too-close" accident. In long queues this type of accident may occur in excess of one block distant from the intersection being reviewed. This occurrence is felt to be rare and would be recorded in a similar manner for both the before and after data.

One interesting aspect of motorist safety at split phase signals are the opinions expressed by engineers, police and motorists at large. The outstanding fact in reviewing such data is that it is undoubtably based on opinion rather than experience. For example, the

Canadian Manual (1) in the 1960 edition only remarks concerning extended green phases were objections namely:

1. waiting vehicles will seriously reduce capacity unless separate turning lanes are provided.

2. drivers waiting to turn cannot tell when movement from the opposite direction is stopped.

3. since two clearance intervals are required, it is equivalent to three phase operation.

However, the 1967 meetings on the same subject indicated a reversal of the former standards with most members recommending the use of extended phases.

Generally, safety arguments concerning lead and lag phases are:

A. <u>Lead</u>

<u>for</u>

1. Left turns take place across the path of stationary vehicles.

2. Left turn starts from a stop.

<u>against</u>

1. Opposing direction traffic may start when seeing advance phase traffic move.

2. Pedestrians require special phases to prevent their crossing until left turns completed.

B. Lag

for

1. Movement takes place well in pedestrian clearance phase.

2. Is a natural movement as most left turns take place on amber phase.

against

1. Opposing traffic clearing on amber is in conflict with turning traffic facing a green.

Observations from Edmonton Police officers have been based on observation of the operation and generally favor the extended or lag green. Surprisingly though, Edmonton police officers in almost all cases cited the intersection of 127 St. - 125 Ave. as an example of a safe operation and 103A Ave. - 101 St. as an example of an unsafe operation, whereas a review of accident data suggests the opposite to be true.

Motorists in general opposed flashing operations from a safety point, particularly during the introductory period. Telephone calls to the Traffic Engineering office

plus interviews with motorists concerning flashing phases seldo were favorable. This may point to the fact that motorists are unaware of the efficiency aspect of the signals but the safety aspect is obvious and of concern to them. Opinion reviews indicate that the motoring public in Edmonton prefers the extended left turn phase over the two phase or advance phase, but prefers a three phase over an extended phase signal. The argument presented was almost invariably safety.

The procedure utilized to compare the differing signal systems was to compare equal time period accident data before and after the signal conversions. The after period was the controlling factor and varies from six to 31 months. Both the total accident rate and the value of damage done were compared by use of a Poisson distribution. These data are presented in TABLE X below.

The accident numbers at each intersection were reduced to accidents per six month rate and then before and after accident rate and annual accident costs were compared utilizing a Poisson distribution. Hom's (12) level of service procedure was utilized to determine operating level of service of each intersection from TABLE IV.

TABLE X

BEFORE & AFTER ACCIDENT RECORD

Location (Level of service)	BEFORE Phase	BEFORE Lt. Acc.	BEFORE Total Acc.	BEFORE Acc./6 mo.	BEFORE Cost 1000	BEFORE ADT	Time Prd.	AFTER Phase	AFTER Lt. Acc.	AFTER Total Acc.	AFTER Acc./6 mo.	AFTER Cost 1000	AFTER ADT	SIGNIFICANCE Poisson Acc.%	SIGNIFICANCE Poisson Cost	SIGNIFICANCE Chebyshev Acc.	SIGNIFICANCE Chebyshev Cost
142St.-St.Pl.Rd. (E)	3Ø	-	28	13	7	21	13 Mo. (Nov/68)	lag	5	38	17	13	23	89.05	98.72	20.4	12.3
97St.-103AAve. (E)	3Ø	-	54	11	18	16	30 Mo. (July/67)	lead	16	70	14	26	17	85.40	97.18	13.6	30+ (12.2)
127St.-118Ave	3Ø	1	46	13	17	10	21 Mo. (June/68)	lag	3	37	10	11	14	25.17	96.78	5.8	7.8
Jasper-109St. (A-C)	3Ø	4	130	26	43	22	30 Mo. (July/67)	lead	23	126	25	55	23	50.06*	91.65		
109St.-100Ave. (A-C)	2Ø	1	80	16	26	10	30 Mo. (July/67)	lead	-	42	8	11	12	99.63	100.00	8	9.8
97St.-JasperAve. (D)	3Ø	-	48	10	8	14	30 Mo. (July/67)	lead	18	46	9	4	18	70.60	97.86	3.6	3.4
95St.-118Ave. (A-c)	2Ø	1	25	12	8	10	24 Mo. (Feb.68)	lag	-	19	9	5	14	97.87	93.19	5	2.4
101St.-103A Ave. (E)	3Ø	-	84	17	21 (8)	16	30 Mo. (July/67)	lead	17	88	18	30 (12)	17	65.50	93.62	25.2	13.6+
127St.-125 Ave. (E)	2Ø	12	56	9	-	11	36 Mo. (June/66)	lag	14	130	21	25	14	99.98	-		
97 St.-118Ave. (D)	3Ø	-	42	12	11	19	21 Mo. (Mar/68)	lag	6	54	15	17	22	84.44	73.63	19.6	17.6
116St.-100Ave. (E)	3Ø	-	4	2	7	7	12 Mo. (Nov/68)	lag	-	5	2.5	.8	8	71.14	-	4.8	

*Accidents per year used.
+Cost/yr used

The Poisson distribution gives a percentage probability that accidents changes from the normal through other than random occurrence. i.e. a 72% figure means that there is a 72% probability that accidents increased due to signal changes.

For Poisson distributions, Chebyshev's formula can be utilized to determine the two standard deviation range. (For Poisson distribution the variance equals the mean, i.e. $u = \sigma^2$ hence $u \pm 2\sigma$ is the two standard deviation range).

None of the intersections exceed two standard deviations indicating significant changes are questionable.

Hom's evaluation reveals that high accident locations are operating on level of service E (i.e. 97St. - 103A Ave.
101St. - 103A Ave.
127 St. - 125 Ave.)

The exceptions are:

1. 116 St. - 100 Ave. which operates at level E, but has recorded only 4 accidents per year.

2. Jasper Ave. - 109 St. indicates a level of service A - C considering the EW movements. The intersection does operate on a level E operation NS and this is the contributing factor to accidents.

The eleven intersections considered in the before and after review of TABLE IV have individual traits which may have affected the accident results, therefore each of these intersections is reviewed to clarify the tabulated results.

1. Two Phase Signals with Left Turn Phases Added:

a. Advance Phases:

i. 109 St. - 100 Ave.

This intersection operates at level of service A - C. The before and after period are of 30 month duration. In the before period, 81 accidents occurred with value of damages being estimated at $26,000.00. In the after period, 42 accidents were recorded at an estimated value of $11,000.00. The Poisson comparison indicates a 99.63% likelihood that the after period accident rate was decreased.

In addition to the original changes, geometric changes were introduced at approximately the signal change over time. It is the author's opinion that although the geometric change is of significance, the signal change certainly did not create a hazardous condition. No left turn accidents were recorded.

b. Extended Phases:

i. 95 St. - 118 Ave.,

The intersection was converted in Feb. 1968 to allow a westbound left turn. The signal operated in a level of service A - C both before and after the conversion. One accident involving a left turn in the special phase direction was recorded before the conversion and none after. While a vehicle increase from 10,000 ADT to 14,000 ADT was detected, before and after totals indicate 25 and 19 accidents respectively. The Poisson analysis indicates an 97.87% likelihood that a significant reduction in accidents has been realized.

2. Three Phase Signal Reduced to Two and One Half Phase Signals:

1. Advance Phases:

i. 97 St. - 103A Ave.,

Volume and geometrics combine to dictate a level of service E at this intersection. The road is reduced from a three lane eastbound roadway to a two lane road with heavy left turn in the intersection. The volume recorded is 17,000 ADT. The accident record after the initial change led to two innovations in signal timing, namely:

- A delayed pedestrian signal for crossings across the left turn movement.

- The clearance interval between the end of the advance flash and the opposing green is adjusted to consider the starting response of the opposing traffic.

Accident records indicate Before and After records of 54 and 70 respectively for the 30 month comparison periods. The Poisson analysis suggests that there is a 85.40% chance that the increase is due to the signal change, and a 97.18% chance that the accident cost increased.

The three phase operation had no left turn accidents and the 2½ phase signal had 16 in the study period. The left turn accidents were concentrated in the first twelve months of operation. However, enough data is not available to determine accident rates since pedestrian and clearance changes have been made. Reviews would suggest that conditions at this intersection would dictate the conversion from advanced to extended phasing for the left turn.

ii. <u>Jasper Ave. - 109 St.</u>

This intersection is probably one of the busiest in the city. Prior to July 1967, separate moving phases

were displayed for east and west bound traffic. After July an advance phase was installed for eastbound traffic. Initially, westbound left turns were banned. However, this restriction was removed in 1969. Prior to 1967 N-S left turns were banned during peak hours. Geometric changes during 1967 allowed left turn bays and the ban was removed. The pre change east-west ADT was 22,000 and the post change ADT is 23,000. The accidents occurring for a 30 month period before 1967 were 130, with the 30 month period since 1967 being 126. The most marked increase in accidents involved the N-S left turns.

The Poisson comparison suggests that there is only a 50.06% chance that there was an accident increase. The volumes are relatively close and it is suggested that no signicant change could be detected.

The E-W left turns were 4 before the conversion and 23 after.

The significant point in this intersection accident record is the fact that before the timing change the east west legs were below capacity. The change in timing gone, a more equitable amount of green time reducing congestion and hence accidents have not increased in total.

iii. <u>97th St. - Jasper Ave.,</u>

This is a T intersection with the east west movement. The accident record indicates a before and after record of 48 - 46 respectively, and ADT of 14,000 and 18,000 before and after the change. Here, again, the additional east west green time and resulting reduction in congestion presented an increasing accident rate.

The left turn accident figure increased from 0 before to 18 after the change. However, the Poisson analysis of cost changes for accidents suggests 97.86% chance that accidents costs were reduced and the reduction is outside 2 standard deviations suggesting a significant reduction in costs.

2. <u>Extended Phase:</u>

i. <u>127 St. - 118 Ave.</u>

This intersection was subject to intense congestion during peak hours, particularly during the morning period. Separate phases were provided for North and South bound movements. In Jan. 1968 an extended phase to allow southbound left turns was added and the northbound left turn was banned. The ADT before the change was 10,000 VPD north and south and is now 14,000 VPD north and south. The accident history is before 46 accidents during a 21

month period and 37 since. Considering the congested state of the intersection, the banning of the northbound left turn became a necessity. Such a restriction should be considered on extended left turn phases. The left turn history indicates 1 left turn accident before the change and 3 since.

ii. 97 St. - 118 Ave.,

This intersection originally had separate east west phases and handled an east west volume of 19,000 VPD. Since the addition of an extended eastbound phase, simultaneous east west movements and a westbound left turn ban, the east west ADT is 22,000 VPD. The accident record is 42 accidents during the 21 months prior to change and 54 accidents in the 21 months since the change.

The capacity improvement can be seen in the ADT figures. However the intersection would still be classed as congested. Thus the left turn ban is a necessity.

The Poisson analysis indicates a 84.44% chance of accident increase due to the change. Left turn accidents increased from 0 to 6.

iii. 116 St. - 100 Ave.

Originally a three phase signal with separate east west phase 7000 ADT east west were handled with an accident history of 4 accidents occuring during a 13 month period. Since the change, ADT has increased to 8000 and accidents for the 13 month period were 5. The intersection has ample capacity and no turning restrictions were imposed. The Poisson review suggests, due to the small totals, that a 71.14% chance exists that the accidents have increased.

3. SPECIAL CASES

a. Double Left Turn Extended Green:

i. 142 St. - Stony Plain Road:

The high westbound left turn has demanded a double left turn movement. Originally separate east west phases were installed. During a 13 month period, 28 accidents occurred and 21,000 VPD travelled east west. The signal was converted to an extended left turn phase and the east bound left turn banned. For the 13 month period since the change, 38 accidents have occurred and 23,000 VPD have been handled. 5 of the 38 accidents involve

left turns. The Poisson analysis suggests a 89.05% chance of accident increase.

This intersection is severely congested and high delays were not uncommon. Observations since the change indicate that very few vehicles now turn from the extra left turn lane.

ii. <u>127 St. - 125 Ave.</u>

An extended eastbound double left was installed in June 1966, in place of the previous 2 phase signal. This was the first flashing phase signal in the city. The before and after accident history for 36 months is 56 before and 130 after. However, there were 12 left turn accidents before and 14 after. The high number of accidents is due primarily to lane usage violations i.e. straight through from left turn lane. The Poisson check suggests a high likelihood that a significant increase in accidents has occurred.

iii. <u>103A Ave. - 101 St.</u>

103A Ave. is heavily congested at its intersection with 101 St. Eastbound geometry allows a left turn bay, adjacent to this is a through and left lane. Originally separate phases were allowed for east and

west direction. In July 1967, an advance double left was introduced which in turn followed by a simultaneous east and west green. Accidents before and after are 84 and 88 respectively for a 30 month period with 0 vs. 17 for the special left phase. The increased east west capacity seems to be the main factor in the accident record. ADT before and after are 16,000 and 17,000 VPD respectively in the east west direction. A 65.5% chance that an increase occurred is determined.

One obvious factor in this review is the increase in left turn accidents occurring when three phase signals are converted to 2½ phase signals. However, as shown in TABLE XI below, the overall accident picture is not significantly changed. It is suggested that the left turn accident increase should not be taken out of context by opponents of change. One must conclude that the signal introduces a left turn accident possibility, but that the increase in left turn accidents is offset by reduction in other types of accidents, probably follow too close accidents caused by congestion.

One point that has not been adequately resolved in this study is the rate of increase as compared to volume

TABLE XI

3 PHASE TO 2½ PHASE ACCIDENTS

Intersection	Left Turn		Total		Costs ($1,000)		Injuries	
	Before	After	Before	After	Before	After	Left	Other
97 St.- 103A Ave.	0	16	54	70	18	26	1	15
109 St.- Jasper	4	23	130	126	43	55	4	62
97 St. - Jasper	0	18	48	46	8	4	-	16
127 St.- 118 Ave.	1	3	46	37	17	11	5	15
97 St.- 118 Ave.	0	6	42	54	11	17	5	13
116 St. - 100 Ave.	0	0	4	5	.7	.8	0	10

increase. Another major factor which should be considered is the fact that accident volumes are generally increasing. The City annually reports an increase of 15 - 20% in its accident rate per year. This annual increase should have been allowed for in the analysis. However, since the exact increase was not known, no allowance for increase was made.

GENERAL DISCUSSION

The introduction of the flashing phases was made in

1966 and inquiries as to their meaning are still being received in the Traffic Engineering office. This would indicate that some of the accidents could be attributed to confusion or misunderstanding on the part of motorists. Unfortunately this aspect is not recorded, and although the phases have been utilized in Edmonton for four (4) years, they can still be considered in the introductory stage. This will only be clarified when the phases are nationally adopted and utilized. The introduction of flash phase signals should be accompanied by as intense a publicity campaign as can be afforded, and such a campaign should be carried out on a regional basis.

CHAPTER VI

CONCLUSIONS

The general purpose of this investigation was to review the split phase left turn and to develop guide lines for the use of such phases. The conclusions drawn are presented in this portion of the thesis.

A. OPERATIONS

1. At High left turn two phase intersections higher turning capacity and through capacity for the turning direction traffic can be provided if special phasing is instituted. Split phasing should be considered ahead of three phase signals.

2. Three phase signals can be reduced to split phase timing and provide good capacity, particularly if the three phase signal was installed due to a one direction heavy left turn.

3. Pedestrian Walk phases should be delayed 2 - 3 seconds after the steady green commences on lead phase signals.

4. Edmonton motorists recognize and comprehend the flash green left turn phase.

5. The 2 way green portion of the signal can and is being used for left turn movements when opposing volumes allow.

6. Two phase intersections displaying high turning volumes on yellow or red phases should be reviewed for special phases (2 per phase over a 1/2 hour period is a rough guide (8).

7. In areas where left turns are required at certain times only, extended split phases should be utilized and can be added either by time clock or presence detector operation.

8. Opposing left turns should be banned for extended phase signal installations.

9. Lead left phases should be considered at intersections which operate in the level A-C range.

10. Green clearance phases should be utilized in lead phase signals. The length of the clearance phase should consider the starting response of the opposing queue.

11. When opposing volumes in an intersection exceed 1000 VPH, and one leg has a high left turn movement, delay will be reduced for the left turning traffic by introducing a special turning phase. Below the 1000 VPH volume, delay in the intersection would be increased.

12. Lead phases will offer less delay than Extended or three phase signals. However, the extended phase may be dropped during off peak periods and should be considered.

13. Lead phases are preferable to lag phases if an opposing left movement is required.

14. Extended green phases lend themselves to intersections operating above Level of service - C.

15. Extended green phases are recommended if a left turn bay is available.

B. STARTING RESPONSE

1. The starting response of Edmonton motorists are similar to that determined by George & Heroy (7) for New Orleans motorists.

2. The location of the ripple indicating simultaneous starting in the queue is at the fourth vehicle in the flash queue as opposed to the sixth in steady green queues. This indicates that the motorists are more prepared to start at this location. This is attributed to the drivers familiarity with the intersection as motorists who appeared confused, stopped rather than proceeding quickly through the intersection.

3. The comparison of actual to simulated starting response indicates that the actual start is slightly quicker than that estimated and that this may affect field comparisons to simulated results.

4. The starting response data was recorded during summer months. Winter and rainy weather response is undoubtably

slower and in countries experiencing long periods of icy roads, special consideration of reduced starting response should be made in signal timing.

C. LEFT PHASE WARRANTS

1. The 10 - 20% envelope utilized in the Uniform Traffic Control Devices Manual for Canada (1) approximates the limit of 2 phase left turn capacity in the 450 to 700 VPH opposing traffic range. The areas below and above this range should have a warrant which is the reverse of the 10 - 20% envelope i.e. smaller above 700, larger below 450.

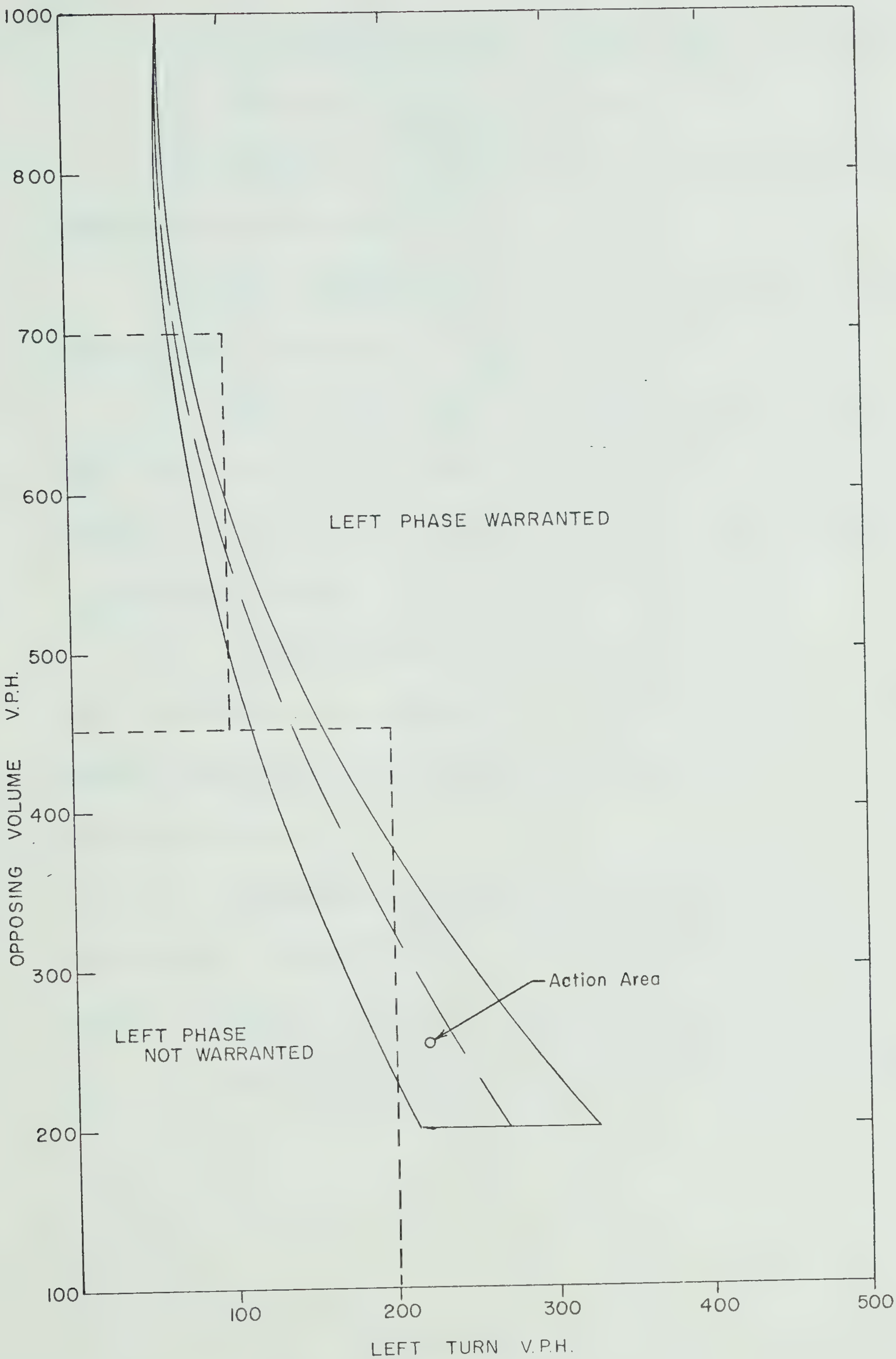
2. A left turn phase warrant utilizing the following graph, FIGURE 15 or if the following parameters are exceeded, is recommended:

OPPOSING THROUGH	LEFT TURN
0 - 450 VPH	200+ VPH
450 - 700 VPH	100+ VPH
700+ VPH	60+ VPH

D. SAFETY CONCLUSIONS

It is concluded that when split phase signals are being considered, this basic data is required:

1. A capacity review of the intersection.



Left Turn Phase Warrant Chart

Figure 15

2. The requirement for opposing left turns be reviewed.

3. Pedestrian crossing volumes.

The answers to the questions posed at the outset of the Safety Report section are:

1. Split phases are safer than two phase operations, particularly congested two phase signals.

2. Split phases are comparable to three phase signals for safety only if the signal is operating in the level A - C. Extended left turn phases with opposing lefts banned display a favorable accident to three phase signals.

3. A change from two phase to split phase, will probably have a reduction in accidents. A change from three phase to 2½ phases will show an increase in left turn accidents, but a similar overall record.

4. Lag phases with opposing lefts banned are safest. Lead phases are preferable to lags with opposing lefts not banned. However, level of service is of prime importance.

5. Split phasing has little effect on pedestrian safety.

CHAPTER VII

RECOMMENDATIONS

1. Research concerning starting response should be pursued since phasing appears to affect response. Weather and pavement conditions would also have an effect on response. This in turn would affect the signal timing, detector spacing and capacity of intersections for signals experiencing long periods of inclement weather.

2. A North American standard left turn indication is required. The use of a left arrow plus a green ball is easily understood and is recommended. The use of the flashing green arrow conforms to this display plus imparting the necessity to hurry.

3. Research into the most effective method of introducing control device changes and publicizing traffic device meanings is required.

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APPENDICES

APPENDIX A

CAPACITY CALCULATIONS

VOLUME CAPABILITIES OF INTERSECTIONS

1. 82 St. - 115 Ave. P. M. Peak.

Data:

Northbound	left	0	
	thru	560	
	right	99	total 659
Southbound	left	144	
	thru	286	
	right	13	total 443
Westbound	left	69	
	thru	124	
	right	80	total 273
Eastbound	left	150	
	thru	293	
	right	13	total 456

Utilizing the CGRA Uniform Traffic Control Devices Manual method to determine timing

NBD equivalent volume = Ve $= \left(\frac{V+0.5H+0.6L}{N}\right)$

$$= \frac{659 + 0.5(1) + 0.6(0)}{2}$$

$$= \underline{329}$$

SBD equivalent volume

$$= \frac{443 + 0.5(1) + 0.6(144)}{2}$$

$$= \underline{264}$$

WBD equivalent volume

$$= \frac{273 + 0.5(1) + 0.6(69)}{2}$$

$$= \underline{157}$$

$$\text{EBD equivalent volume} = \frac{293 + 0.5(1) + 0.6(150)}{2}$$

$$= \underline{191}$$

Timing design - utilizing CGRA manual are:

a. Two Phase

N-S green time = 16 sec.

E-W green time = 14 sec.

clearances 2 @ 4 sec=8 sec.

Pedestrian time .25C (C = 50')
= 12.5 sec.

plus 8 sec. walk timing = 20 sec.

Signal timing equals N-S green 20 sec.
E-W green 20 sec.

2 yellows @4 = 8 sec.

Total Cycle = 48 sec.

G/C = 50 - 50

Note that the SBD left turn exceeds 20% of the through volume in the heavy direction ie.560 NBD.

b. 2½ Phase

N-S green	same as 2 phase.
E-W green	same as 2 phase.
Clearance	same as 2 phase.

plus left turn phase 13 sec.

Ve = 144 Sum of equivalent volumes 450 VPH.

plus additional clearance phase 4 sec.

Total Cycle = 6.5 sec.

c. 3 Phase

NBD Green = 19 sec.
329 vs. 450

SBD Green 264 vs.510 = 17 sec.

EW Green 191 vs. 580 = 16 sec.

plus three yellows @4= 12 sec.
64 sec.

Utilizing minimum pedestrian times

@ 20 sec. leg = 60 sec.
clearance 12 sec.
72 sec.

Capacity Analysis (Nomograph procedure)

2 Phase signal - 82 St. - 115 Ave.

N-S	E-W
Wa = 25'	25
%R = 15	30
%L = 22	30
Metro Size = 500,000	500,000
G/C = 0.50	.50
%Tr.= 0	0 (assumed)
CD = 880 VPH	Cd = 930

2½ Phase

N-S Green	EW	Flash
as above except		
L = 0		
G/L = 0.31	= 0.31	= 0.20
Cd = 800 VPH	=720 VPH	= 200 VPH

3 Phase

N Grn	EW	S Grn
G/C = .29	.25	.26
Cd = 780 VPH	650 VPH	750 VPH

2. 97 St. - 103A Ave.

Data:

Northbound	left	0	
	thru	459	
	right	43	total 502
Southbound	left	0	
	thru	396	
	right	221	total 617
Eastbound	left	249	
	thru	649	
	right	43	total 988
Westbound	left	0	
	thru	413	
	right	33	total 446

CGRA Equivalent volumes:

$$NBD = \frac{502 + .5(1) + .6(0)}{2}$$

$$= \underline{251}$$

$$SBD = \frac{617 + .5(1) + .6(0)}{2}$$

$$= \underline{308}$$

$$EBD = \frac{988 + .5(1) + .6(249)}{2}$$

$$= \underline{568}$$

$$WBD = \frac{446 + .5(1) + .6(0)}{2}$$

$$= \underline{223}$$

Timing design - CGRA manual.

a. 2 Phase

NS green time = off chart in excess of 132 sec.

i.e. 500 vs. 850 = 121 sec.

EW green time = off chart as above.

b. 3 Phase

NS green time = off chart

E bound = off chart

W bound = off chart

c. $2\frac{1}{2}$ Phase

NS = off chart

EW green = 28 sec.

EBD left = 36 sec.

If it is assumed that ½ the left turn can occur on the solid green phase then EBD left required is 16 sec.

Then total EW = 28 + 16 = 44 sec.

and NS green is arrived at by proportions i.e. $\frac{1000}{600} = \frac{44}{x}$

NS green is then 26 sec. giving a total cycle of

E Flash	16 sec.
Cl.	2 sec.
EW Green	28 sec.
Cl.	4 sec.
NS Green	26 sec.
Cl.	4 sec.
TOTAL	80 sec.

2 Phase timing based on G/C ratio and minimum pedestrian clearances

NS @ .33 & 22 sec.

EW @ .50 & 30 sec.

plus clearances 2@4= 8 sec.

60 sec.

3 Phase timing based on G/C ratio and pedestrian clearances

NS @ .25 & 20 sec.

W @ .25 & 20 sec.

EW .50 & 40 sec.

Plus 3 @4= 12 sec.

92 sec.

97 St. - 103A Ave.

2 Phase Signal

	NS	EW
W_A	= 25'	25
%R	= 36	5%
%L	= 0	25
Metro	500,000	-
G/C	= .40	.60
% Tr	= 0	0
CD	= 900	940

2½ Phase Signal

NS	EBD Fl. E Left	E Thru	EW Green & Thru
Same except			L% 10%
G/C = 0.31	G/C = .20		.34
CD = 810 VPH	200	600 VPH	820 VPH

3 Phase Signal

	NS	EBD	WBD
	G/C = .30	.40	.30
	CD = 800	880	780
TRIAL #2			
	G/C = .25	.50	.25
	CD = 750	980	740

APPENDIX B

2 PHASE

LEFT TURN VOLUMES

TWO PHASE LEFT TURN VOLUMES

Intersection	Opposing Volume	Left Turn
Jasper - 116 St.	394	68
	439	89
	914	25
	420	108
	378	82
	518	67
109 St. - 111 Ave.	665	62
	522	101
	260	84
	400	74
124 St. - 111 Ave.	491	59
	229	135
	300	177
	572	57
	200	81
118 Ave. - 124 St.	112	128
	111	212
	970	9
	788	42
	1215	17
	500	30
	460	48
100 St. - 101A Ave.	459	89
	500	100
	300	50
142 St. - St. Pl. Rd.	907	123*
	291	685*
	451	46
124 St. - 107 Ave.	522	81
	332	119
	847	18
	426	123
	608	60
	894	42

Cont..

Intersection	Opposing Volume	Left Turn
101 St. - Kingsway	663	278 ⊙
	472	313 ⊙
111 Ave. - 97 St.	550	11
	260	76
	328	67
	342	171
	718	59
115 Ave. - 82 St.	340	104 △
	560	144 △
	293	70
	124	150
	226	36
75 St. - Argyll	469	142 △
	422	487 △
50 St. - 118 Ave.	435	85
	424	83
	410	111
	391	112
82 St. - 118 Ave.	352	124 ⊕
	286	165 ⊕
	215	126 ⊕
149 St. - St. Pl. Rd.	463	31
	224	136 +
	510	28 +
	251	268 +
	564	114 +
116 St. - 104 Ave.	266	70
	376	110
	1079	10
	313	92
	389	88
	382	128
	937	57
	462	42

Cont...

Intersection	Opposing Volume	Left Turn
124 St. St. Pl. Rd.	330	13
	289	294
	202	103
	982	11
	325	67
	464	176
	888	30
101 St. - 107 Ave.	654	116 ⊙
	580	163 ⊙
	567	22
	395	64
	489	55
	865	42
109 St. - 107 Ave.	569	58
	838	62
	447	53
	542	51
	733	84
97 St. - 107A Ave.	593	39
	252	75
	728	29
	340	173
	709	66
	276	130
	393	195
	715	22

⊙ Thru & right turn phase followed by left, thru and right phase.

△ Advance flash phases

⊕ Three Phase signal

+ Double left turn